

PROCEEDINGS
OF
SYMPOSIUM ON MUDFLOWS
IN JAPAN AND INDONESIA

JULY, 1978

PUBLIC WORKS RESEARCH INSTITUTE
MINISTRY OF CONSTRUCTION,
JAPAN

Preface

The first Japan-Indonesia Symposium on Volcanic Debris Flow Treatment which based on the Scope of Work on Japan-Indonesia Joint Study Plan on the Sabō-Works in the Volcanic Region was held in Tokyo from March 27th to 28th in 1978.

It gives us great joy to see of published proceedings of the symposium. This proceedings are edited by member of the organizing staff. All papers are expressed in English and Japanese, and made in respective prints.

Appreciation due to the lecturers who submitted the manuscripts, editors who edited and translated from English into Japanese.

Yoshiro YOSHIOKA
Chief, Organizing Staff of the Symposium
Director, Erosion Control Dept.
Public Works Research Institute

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1. SYMPOSIUM SCHEDULE

Time : March 27 ~ 28 1978

Place : TORANOMON-KYOSAIKAIKAN 2nd FLOOR

Theme : Volcanic Debris Flow Treatment

1-1. Program

Monday, March 27		Tuesday, March 28	
10:00	Opening Session <i>K. NAKAZAWA</i> : Official Opening of Symposium <i>Ir. SURAJIL</i> : Response <i>SANADJI</i> : Compliment <i>J. NAKAMURA</i> : Compliment	10:00	<i>Dr. S. Okuda</i> : Mud-flow Dynamics
		10:50	<i>SURYO</i> : Lahars in Indonesia and Counter-measures to Minimize its Hazards
		11:40	Lunch
10:30	Break	13:00	<i>Dr. A. TAKEI</i> : Countermeasure Planning on Volcanic Debris Flow around Mt. Merapi
10:50	<i>SURYO</i> : Nuée Ardente at Merapi Volcano and Precautionary Measures against Volcanic Phenomena	13:50	<i>T. MATSUSHITA</i> : Debris Flow Disaster and its Countermeasure in Japan
11:40	Lunch	14:40	Break
13:20	<i>Y. YOSHIOKA</i> : Recent Study on Volcanic Debris Flow in Japan	15:00	Discussion
14:10	<i>Ir. BAMBANG</i> : Result on Investigation in Mt. Merapi	16:20	<i>Y. YOSHIOKA/Ir. SURAJIL</i> : Proposal for Study in Future
14:40	Break	16:50	<i>M. WATARI</i> : Symposium Closing
15:10	<i>O. YAMAUCHI</i> : Result on Investigation in Mt. Yake and Sakurajima		
15:30	Discussion		
16:50	Closing		
17:00	Reception		

1-2. Opening Address

Organizer of the Symposium

Mr. Kazuto NAKAZAWA

(Director General, P.W.R.I.)

Honorable guests and gentlemen,

In any gathering whatever the objective is, it is customary that an opening address for inauguration is made by a head of the organizing body.

Just because of this custom, I am here to make speech as I am a head of the Public Works Research Institute which is responsible for organizing the Japan-Indonesia Symposium on Volcanic Debris Flow Treatment. I would ask with humiliation all of participants to be kind enough to hear me for a while though I am not a good speaker in English.

Now gentlemen,

You will agree that this Symposium has very valuable implications. Because Japan and Indonesia have been suffered from various disasters due to their natural surroundings through their historical ages, mitigation of these damages seems to have been always given first priority out of various national policies ever since the establishment of their modernized administrations.

One of the damages is caused by torrential river flow being loaded with volcanic debris, which encourages energy of river flow, burying or crushing many houses off. Therefore, it must be quite natural that both countries, under the similar climatological, geophysical and demographical condition, came to agree on collaboration of research and study on the subject, volcanic debris flow, since urgency of mitigation of these damages has been keenly recognized as I said before.

This collaboration scheme was initiated by Mr. Watari of the Public Works Research Institute, who was then the director of erosion control department of the Institute, when he visited Indonesia in 1975.

After three-year negotiation, plan of operation for this collaborative research work was finalized in May 1977. Prior to the finalization of negotiation, country-wide reconnaissance in Indonesia for the collaborative study was contemplated and starting in 1976 it has been implemented. At the same time an observing station was installed in order to obtain necessary data of volcanic debris flow at the foothill of Mt. Merapi of Indonesia, basic idea being the same as Mt. Yakedake in Japan. Outcome of these activities will be presented in this Symposium later.

Now I would like to call attention of my Japanese colleague that we should pay due respect to Indonesian friends who are generous enough to participate to the Symposium after trip as long as tens of thousands kilometers from their home country.

Gentlemen, on behalf of my Japanese colleague I should express my sincere welcome and gratitude to my Indonesian friends, Engineer Surajil who is a chairman today, Engineer Bambang, Mr. Sumitro and Mr. Suryo. Presence of Secretaries of Indonesian Embassy in Tokyo would also surely impress Japanese participants for their dedication to the success of the Symposium.

Before concluding my speech, I would stress that the Symposium could be fruitful only by enthusiasm and elaboration of participant yourself, thus strengthening good relation between Japan and Indonesia, and I believe it surely will.

Thank you for your kind attention.

1-3. Response

Chief of Indonesian Delegation

Ir. SURAJIL

**(Chief, Sub-Directorate of Maintenance,
Directorate of Rivers, M.P.W.E.P.)**

Distinguished Gentlemen,

We are very glad to be present at this first symposium on volcanic debris control in Tokyo in the frame work of the joint survey between Indonesia and Japan and the Mt. Merapi Master plan program.

This symposium is considered important as papers will be presented as the result of coordinated study in Japan and Indonesia. We are now entering the third year of this survey, which will be the last year of our three years cooperation programme.

Three years is in fact a very short time for the purpose of research work. Although much has been done with respect to the counter measures against lahars, as for example, the construction of Sabo-dams, lahar pockets and building of various structures to regulate the flow of dangerous lahars, but still much remains to be done. The formation and nature of lahars, the composition and the mechanics of movement needs further research, which is very important for the purpose of designing engineering structures.

It is regretful to inform you that not much has been done yet with respect to research work in this matter in Indonesia in these past two years, due to difficult circumstances at the job site in our country.

Therefore we are very glad to hear, that the Ministry of Construction in Japan is intending to extend the joint survey programme for one more year, during which time we hope to be able to collect more data on the nature of lahar flow.

It is to be hoped that this symposium will be useful not only for the purpose of transfer of knowledge between both countries, but also for the purpose of the improvement of countermeasures against these dangerous secondary volcanic phenomena.

Thank you!

1-4. Compliment

Embassy of Indonesia (in Tokyo)

Mr. SANADJI
(Minister Counsellor)

Mr. Chairman, distinguished gentlemen.

Allow me first of all to express on behalf of the Indonesian Embassy and Indonesian participants to this symposium, our highest appreciation, thanks and gratitude to the Public Works Research Institute, Ministry of Construction, Government of Japan for their initiatives and efforts in making this Japan-Indonesia Symposium materialized.

Our appreciation is also directed to those who has been actively involved in making this symposium a well organized and well prepared one.

Although I'm not an expert in Volcanology, I've no doubt that this kind of Symposium will have a paramount role in improving the technical know-how in the field of Volcanic Debris flow treatment, in order to prevent disaster which directly or indirectly caused by volcanic activities, become worse.

In this forum a frank discussion as well as exchange of opinions and exchange of experiences of both parties will improve not only the technical know-how in this area but also could improve friendship and understanding among us. I believe, it will be the spirit of us that Symposium is only one of the means to achieve our main objectives that is to put any volcanic disaster under control.

Mr. Chairman, distinguished participants of Symposium, I hope that this Symposium will produce a new idea of cooperation between two nations in this field which finally will also contribute to the safety of human life.

Thank you.

1-5. Compliment

Ministry of Construction

Mr. Jiro NAKAMURA

(Director General, Erosion
Control Department, M.C.)

I would like to celebrate the opening of this symposium for distinguished guests attending here today.

I am really happy to have Ir. Surajil and three distinguished guests from Indonesia today and also many Japanese guests closely related to erosion control engineering in this splendid opening of "Japan-Indonesia Symposium on Volcanic Debris Flow Treatment". And I sincerely admire the Public Works Research Institute for its efforts in sponsoring this symposium.

As you already know, erosion control technology in our country is based on a very long history through which various unique erosion control techniques in our country have been created and successfully applied to prevent disaster by sediment.

But to my regret, we have still many disasters by sediment each year and many lives and properties are being lost, and necessity of erosion control is rather increasing each year.

The cope with this problem, Ministry of Construction is spending tremendous amount of money exceeding 220,000 million Yens each year to promote erosion control work (Sabo Work) while establishing debris flow danger areas as one of overall erosion control measures and vigorously promoting basic researches and investigation on the debris flow to improve the warning and evacuation system.

While we have such problems in Japan, Indonesia also has suffered from many disasters of sediment near the volcanoes including Merapi Volcano. And both countries have conducted joint studies on sediment disaster measures against volcanic debris flow and are now opening the symposium for the debris flow today. This is very meaningful and important and we greatly expect fruitful results from this symposium and sincerely pray the success for you.

Lastly, I hope that Indonesian guests see the current situation of erosion control technology in our country to understand the essence of the erosion control.

And I believe and hope our goodwill between two nations will be further deepened through the erosion control in this times.

Thank you.

2. TREATISE FOR THIS SYMPOSIUM

2-1. Special Lecture Mud-flow Dynamics

Dr. Setsuo OKUDA

(Prof., Kyoto Univ.)

FOREWORD

Studies on dynamics of debris flow in our country have so far been carried out mainly by the university researchers with emphasis on consideration upon the simple models of fundamental phenomena. At the present stage, they are not yet able to describe the actual debris flow very well nor able to explain the debris flow from generation to stop with one consistent model. However, in order to understand the real nature of the debris flow phenomena and thus formulate scientific countermeasures, it is absolutely necessary to grasp the rules governing the phenomena and to exert efforts in pursuit of quantitative expression of the phenomena. This Symposium, where I am allowed to report to you the specific processes and results of such efforts, provides a good opportunity for me to hear valuable comments and useful advices from the distinguished personnel gathering here with much practical knowledge and experience at various sites.

However, the speaker, being not qualified for introduction of all the dynamical studies carried out extensively and actively at present, is going to summarize mainly the works of the research group in our country to which the speaker belongs and introduce them with some personal comments added and care for their correspondence to the actual debris flow.

DYNAMIC FEATURES OF DEBRIS FLOW

It is very difficult to define strictly dynamically what is a debris flow. But, here, for the sake of limiting the research works or the objects of introduction, a more or less specific view will be given in the following.

Debris flows occur on mountain slopes everywhere with heavy precipitation on globe. And they are expressed in different terms as phenomena which cause serious disaster. As an academic term, the "debris flow" in the mass wasting according to a recent geomorphological classification (such as, for example, by D.J. Varnes¹⁾; see Fig. 1) is a most appropriate expression, and here it is classified as a phenomenon of a mixture of rock, soil and clay with a sufficient content of water flowing at a rapid speed.

In a more dynamical expression, it may be given as a phenomenon of a mixture of solid particles having a wide range of grain size distribution and water taking a form of "massive transport" and flowing at a considerably rapid speed.

Further, as an expression to distinguish the massive transport from the individual transport from a view of fluid mechanics it may be expressed as a "phenomenon of a group of solid particles having a high volume concentration being transported in a condition under which the dynamical effects such as interactions of particles to the flow (interference of boundary layer or wake), intermittent collision of particles with one another and continuous contact of particles with one another are predominant over the effect of the flow upon the individual particles."

For an objective of dynamical research of debris flow, the place or time of its generation is little concerned but the form of flow is important.

- 1) D.J. Varnes; Slope Movements in the Western United States, Mass Wasting, 4th Guelph Symposium on Geomorphology (1975).

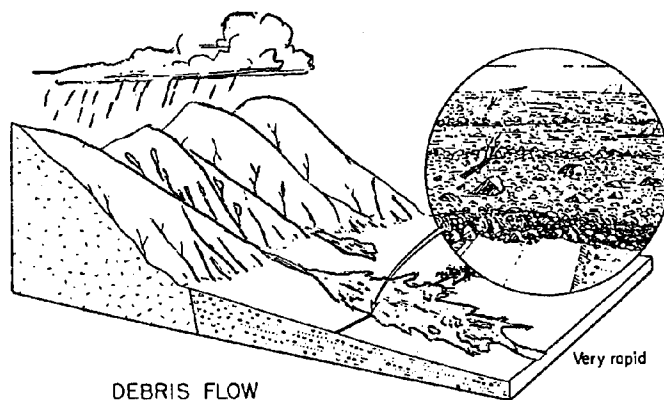


Fig. 1 Diagram of a debris flow issuing from a mountain valley onto lowlands
(after D.J. Varnes ¹⁾)

In short, a phenomenon of a mixture of a very wide range of grain size distribution of debris (rock, sand and clay) and water flowing in a form of massive transport at rather high speed will be taken as a feature of the debris flow we are going to discuss here.

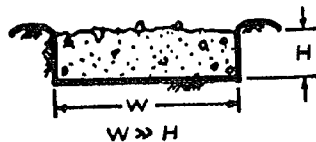
PROCESS OF GENERATION OF DEBRIS FLOW

Debris flows undergo generally a number of transitional processes in the course from generation to stop such as acceleration, deceleration or increasing or decreasing mass of the flow. It is difficult to consider these processes integrally, while there is an aspect of the processes being dynamically classified into considerably heterogeneous phases. Thus, here, they are classified into the processes of generation, flow and stop, and in this section, the generation will be taken up first.

For generation of a debris flow, start to movement downward of a group of debris on a slope (mountain-side or stream bed) and its transformation into a massive transport form through rupture of the sediment structure and inclusion of water are requisite. For the dynamical consideration on the start of the debris group at the first stage, the theory of slope stability established in the field of soil mechanics is available.

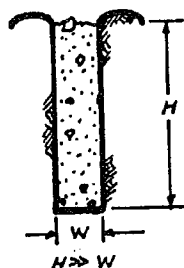
For example, the critical conditions for a debris deposit having an internal frictional angle ϕ , cohesion C and density γ to be present stably on a slope having a slope angle δ are tested well, and for various geometric forms of the deposit cross-section, the results²⁾ such as shown in Fig. 2 are given.

2) J.D. Rodine, et al; Analysis of Mobilization of Debris Flow, Army Research Office—Durham (1974), p. 179.



$$H = C / \{ \gamma \cos \delta [\tan \delta - \tan \phi] \}$$

A



$$W/2 = C / \{ \gamma \cos \delta [\tan \delta - \tan \phi] \}$$

B



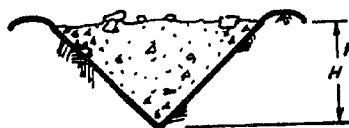
$$R = 2C / \{ \gamma \cos \delta [\tan \delta - (4/\pi) \tan \phi] \}$$

C



$$H = 2C / \{ \gamma \cos \delta [\tan \delta - (4/\pi) \tan \phi] \}$$

D



$$H = 2.8C / \{ \gamma \cos \delta [\tan \delta - (4/\pi) \tan \phi] \}$$

E

C, apparent cohesion.
 γ , unit weight of debris.

ϕ , apparent friction angle.
 δ , slope angle.

Fig. 2 Channel cross-sections and formulas for critical dimensions.

- A. Rectangular channel, width much greater than depth.
- B. Rectangular channel, depth much greater than width.
- C. Semi-circular channel.
- D. Rectangular channel, width equal to twice the depth.
- E. Right triangular channel.

(after J.D. Rodine, et al²⁾)

When the left side of such critical equilibrium formula becomes greater than the right side, downward movement of the mass of debris is commenced. Then, as an actual condition for generation, there may be listed supply of water by a heavy rainfall to produce a ground water pressure to reduce the frictional resistance, giving the drop in ϕ apparently; soaking of water to cause change in the physical properties, decreasing C and $\tan \phi$ substantially; vibration due to impact of flowing water or earthquake to decrease C and $\tan \phi$ apparently; or separate avalanche of a small scale supplying debris to increase H or increase in loading weight, thus breaking the equilibrium.

For the instability of slope caused by supply of water, T. Takahashi³⁾ discussed various cases of smaller C as in secondary deposits such as shown in Fig. 3, derived a conditional formula shown in the drawing for each case and pointed out that the results agreed well with the observations on actual flow in hydraulic experiments.

These conditions are derived from the comparison between working shear stress and resistant shear strength, and determined by many geometrical and physical parameters written under the figures, and the results show that surface run off of thickness h_0 stimulates the occurrence of massive sliding of debris layer.

For lower C and ϕ with higher moisture content upon soaking of water, there are many investigations made of field samples. For example, J.D. Rodine⁴⁾, obtaining curves shown in Fig. 4 and using the equilibrium formula written in Fig. 2 in conjunction, he is considering to predict the beginning of avalanche in use of the so-called mobility index or when the slope becomes unstable at what times of moisture content of the field capacity at the site.

Further, S. Okuda et al.⁵⁾ tested the vibrations of the stream banks when a debris flow moved down in the Kamikamihori Valley of Mt. Yakedake and obtained the diagrams shown in Fig. 5.

3) T. Takahashi; A Mechanism of Occurrence of Mud-debris flows and Their Characteristics in Motion, (in Japanese) Disaster Prevention Research Inst. Annuals, No. 20B-2 (1977) P. 406

4) J.D. Rodine, et al; Analysis of Mobilization of Debris Flow, Army Research Office-Durham (1974), p. 181.

5) S. Okuda, et al; Synthetic Observations on Debris Flow, Part 3, (in Japanese), Dis. Prev. Res. Inst. Annuals, No. 19-B (1976), p. 237.

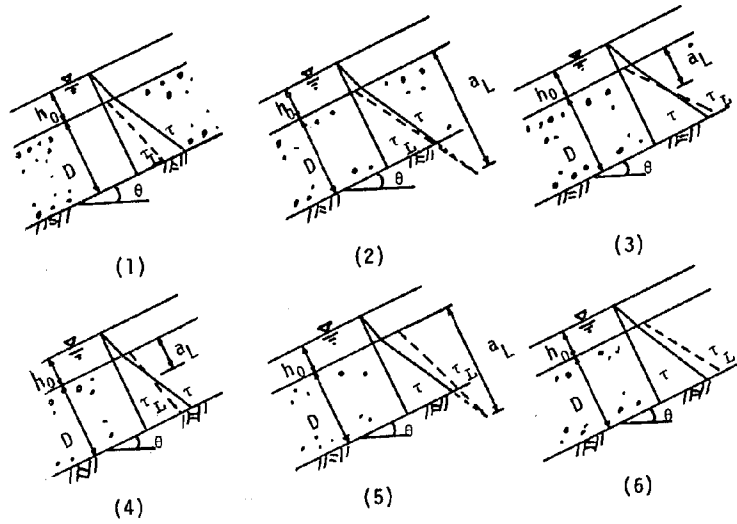


Fig. 3. Characteristic shear stress distribution

τ working shear stress, τ_L resistant shear strength.

Conditions of Flow Initiation (neglecting cohesion)

$$\text{Case (1); } \tan \theta \geq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho} \tan \phi$$

$$\text{Case (2); } \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho} \tan \phi > \tan \theta \geq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/D)} \tan \phi$$

$$\text{Case (3); } \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/D)} > \tan \theta \geq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/d)} \tan \phi$$

θ slope angle, ϕ interval friction angle,

C_* volume concentration of sand or gravel in bed layers,

σ density of sand or gravel, ρ density of water,

d diameter of sand or gravel, h_0 depth of water,

D thickness of deposit layer.

(after T. Takahashi³⁾)

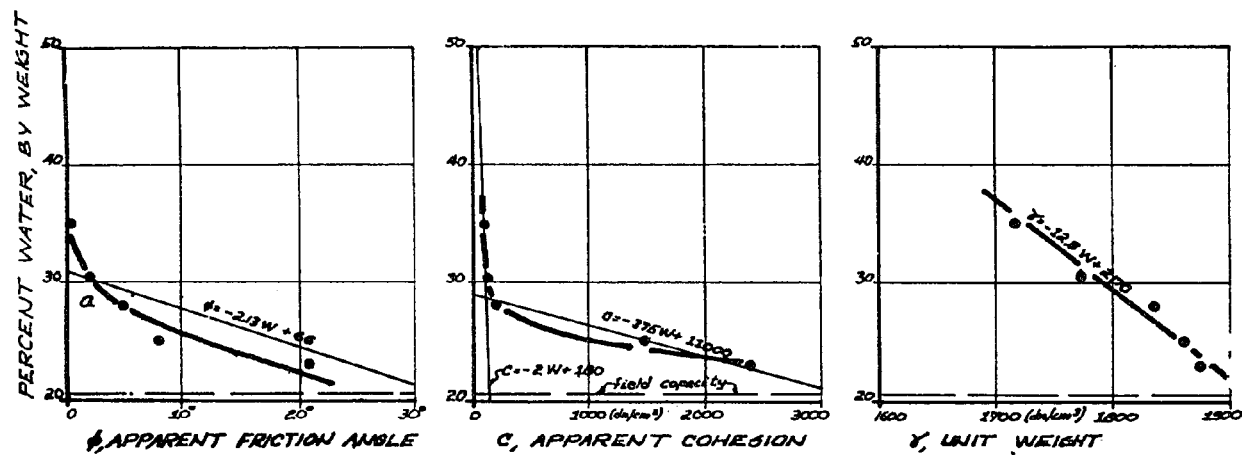


Fig. 4 Apparent friction angle, ϕ , apparent cohesion, C , and unit weight γ , as functions of water content, W , for a sample of debris-flow material from Thompson Creek, Utah.

(after J.D. Rodine, et al²⁾)

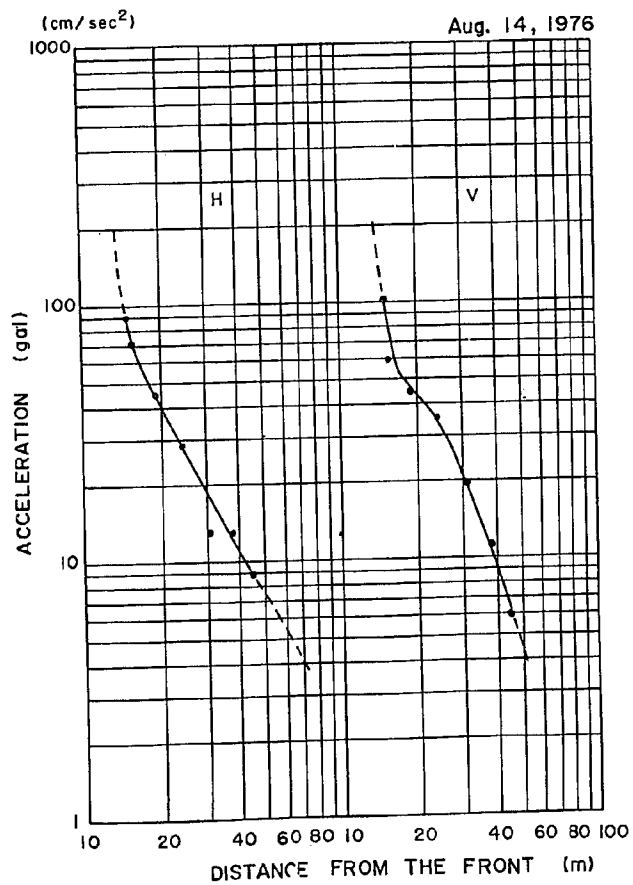


Fig. 5 Acceleration of ground vibration as a function of distance from the head of debris flow, observed at Valley Kamikami by use of vibration transducer MZ3 Type-CA 28Hz made by Walker-Hall-Sears, Inc.

H horizontal component, V vertical component.
(after S.Okuda, et al⁵⁾)

According to the diagrams, it is shown that when a debris flow runs down, a vibration of a seismic intensity of the 5th degree or higher is produced around the leading edge to reduce the values of C and $\tan \phi$ so that the stream bed deposit is apt to be fluidized.

If the debris thus fissuring off and beginning to move downward has a sufficient amount of water supplied, it is enabled to flow in the form of a massive transport at a high speed over a long distance, and thus becomes a debris flow. Otherwise, it remains as a mere slope collapse and stops in a short distance.

It is difficult to quantitatively express the process of supply of water to the debris layer. But, as such process, soaking of the water flowing over the debris layer or a heavy rainfall directly onto the surface into the layer of loosened structure by movement, ejection of a large amount of ground water from fissures in the rock beneath the surface bed, or diffusion of water kept in a loosened part in a state of packing in the debris layer throughout the layer with movement, may be considered. However, in a heavy rainfall, the debris flow is apt to occur not so later than the peak of the rainfall. This suggests that the debris flows are due largely to the surface water fed from a small catchment area in the upper reach of the place of generation or the direct precipitation.

PROCESS OF MOVEMENT OF DEBRIS FLOW

It is generally maintained that the debris flows contain solid particles at a high concentration yet keep a state adapted for flow in that the particles are of different sizes to preclude their interlocking. This means that shallow interlocking occurs when smaller particles fill the voids among larger particles. But, this is not supported well by a quantitative explanation.

T. Takahashi⁶⁾ discussed, in use of a refined hydraulic model, the transitional process or growing of debris flows including deposit debris as then travelled down once they were generated and the flow regime after they came to a steady state.

For the steady flow, he used the Bagnold's semi-empirical formula of expression of the dispersive stress that could be applied where the inter-particle collision effect would be predominant over the viscosity effect of flow and derived a distribution formula of velocities in an open channel and thus obtained the following mean velocity formula.

$$U = \frac{2}{5} \left[\frac{1}{a_i \sin \alpha} \left\{ C_d + (1 - C_d) \frac{\rho}{\sigma} \right\} \right]^{1/2} \left\{ \left(\frac{C_*}{C_d} \right)^{1/3} - 1 \right\} \times \frac{\sqrt{g}}{d} (\sin \beta)^{1/2} h^{3/2}$$

where a_i and $\sin \alpha$ are experimental coefficients appearing in Bagnold's formula; C_d is the concentration by volume of gravel in the fluidized layer; C_* is the concentration by volume of gravel in the deposit layer before motion; ρ is the density of water; σ is the density of gravel particles; d is the diameter of gravel particle; β is the angle of slope of the water channel; h is the thickness of the fluidized layer; and g is the gravitational acceleration.

This formula includes, as variables, not only the geometrical quantities such as layer thickness and slope but the physical quantities such as particle concentration and density and is, therefore, physically excellent over the conventional Manning's and other flow formulas.

6) T. Takahashi; A Mechanism of Occurrence of Mud-debris Flows and Their Characteristics in Motion, (in Japanese) Disaster Prevention Research Inst. Annuals, No. 19-B (1976) p. 409

However, the coefficients appearing in the Bagnold's stress formula do not always take values which are universally applicable. Thus, this stress formula, as being examined by A. Daido⁷⁾, involves difficulty for direct application to the sites for comparison with the values of observation.

Further, the discharge q of water in the fluidized layer of debris flow is greater than the fed discharge q_0 from the upper reach since it joins the water contained in the voids in the deposit layer prior to movement. Thus, upon the rule of conservation of the discharge of water and gravel, T. Takahashi obtained the formula

$$q = \frac{C_* (1 - C_d)}{C_* - [S + (1 - S) C_*] C_d} q_0.$$

where S representing the degree of saturation of water in the voids in the deposit layer.

From the formula, if $S \div 1$ and $C_d \div C_*$, q may be several times greater than q_0 , and this supports theoretically the result of observation that the discharge of debris flow is far greater than that expectable from the water balance of precipitation alone.

T. Takahashi also discussed, in use of a model shown in Fig. 6, the process of an hydraulic bore of a length L including deposited gravel and thus growing as it travelled at a certain velocity U and succeeded in quantitatively expressing the increasing hydraulic bore height h and gravel concentration C_d with downward movement from the continuity of the discharges of water and gravel.

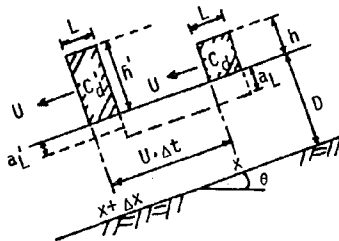


Fig. 6 Increment of the front height along the stream
(after T. Takahashi³⁾)

While the details of these formulas are omitted here, they deftly express the way of h and C_d increasing and reaching to a certain value asymptotically with elapse of time t .

However, in an actual valley, the velocity increases gradually, and in experiments, it is difficult to confirm the constant value of L , so that there are some problems remaining with respect to specific application.

MOTION OF LARGE BOULDERS

In the process of flow described in the foregoing, general motion of gravel was discussed. But, in debris flows, boulders several meters in diameter accumulate at the leading part and are thus carried to create a distinguished raise at that part. This part is also a region of concentration of energy immediately causing serious

7) A. Daido; Private Communication.

damage of debris flow so that it will be taken up specifically for explanation.

Boulders as large as several meters in diameter are not readily moved by a steady flow of water, and for their movement, some other special causes must be considered.

Daido⁸⁾ calculated the force acting upon a boulder located in a water channel having a great slope with a difference in the water level between the upper and lower sides of the boulder and also the moment of rotation and showed that the boulder could be moved by the streamflow alone under a special situation.

H. Suwa and Okuda⁹⁾ calculated the impact force of water flowing down in the form of an hydraulic bore and its leading front coming into contact with a boulder and showed that the force would be as great as four times the drag of a steady flow of the same velocity and that by an abrupt wave of a velocity of 5 meters per second, a boulder of 2 meters diameter could be started to move.

Further, Okuda¹⁰⁾ calculated the force produced by elastic collision of boulders with each other and showed that when a boulder of several tens centimeters diameter flowed down at a velocity of several meters per second and hit another boulder of 2 ~ 3 meters diameter, it could start the other larger boulder to move.

Once boulders begin to move in water upon cumulative effect of such forces, larger boulder is under the influence of greater dispersive stress (by Bagnold as stated above) and is apt to move upward and thus approaches the water surface. As the average velocity of flow is greater nearer the surface, the boulders gather gradually at the front part. M. Hirano et al.¹¹⁾ examined the configuration of, and distribution of flow velocities in the leading part of debris flow and showed that larger boulder was apt to gather faster at the leading part.

Boulders thus gathering at the leading part of debris flow, when they hit an object lying in the path of the debris flow, impart a very great impact force to such object. With respect to the intensity of such force, Okuda¹²⁾ has given a quantitative discussion as set forth below.

Applying the theory of collision of elastic bodies, he calculated the impact force of a spherical rock mass hitting a plane wall in water and obtained the expressive formula

$$P_{max} = \left(\frac{\pi^{1/5} \cdot 5^{3/5} \cdot 4^{2/5}}{3} \right) (p_r + \frac{P_w}{2})^{3/5} (k_r + k_w)^{-2/5} R^2 V^{6/5}$$

where P_{max} is the maximum value of force produced when a spherical rock mass of a radius R hits a plane wall at a velocity V , p_r and p_w are the density of rock and that of water respectively; and k_r and k_w are the modulus of elasticity of rock and that of wall respectively, k being given from Poisson's ratio ν and Young's modulus E by the formula, $k = (1 - \nu^2)/\pi E$.

Applying this formula to the conventional rock mass and concrete wall, when a rock mass of 1 meter diameter hits the wall at a velocity of 1 meter per second, there is produced a force of about 100 tons with one collision. The impact time of collision is order of 10^{-3} sec and maximum contact area is about few tens cm^2 , then impact force changes from place to place and from time to time. It should be noticed that the value of

8) A. Daido; Fundamental Study on Mud-flow(V) (in Japanese) Dis. Prev. Res. Inst. Annuals. No. 8 (1965) P. 317

9) H. Suwa et al; Motion of Large Stone at Mud-flow Front and Flow Pattern of mud-flow, (in Japanese) Dis. Prev. Res. Inst. Annuals. No. 16-B (1973) P. 425.

10) S. Okuda; Elastic Collision of Large Stones in Debris Flow, (in Japanese), Report on Debris Flow Survey (1978). Published by Matsumoto Sabo (in press).

11) M. Hirano et al; On the Moving Process of Debris Flow, (in Japanese) Lecture Print on Symposium of Natural Disasters, 14th (1977), P. 129.

impact force takes several hundreds of times of the value estimated from dynamic pressure of steady flow i.e. $\frac{1}{2}\rho wV^2$. However, this theory should be applied to collision between completely elastic bodies. Actually, therefore, the scope of application should be defined in consideration of the limit of elastic deformation or breaking limit. Anyway, it should be noted that there is a possibility of very great force produced.

PROCESS OF DECELERATION TO STOP OF DEBRIS FLOW

The process of deceleration to stop of debris flows is deeply connected to the artificial control of debris flows. Nevertheless, its dynamical study is in a most retarded state. As the reasons, there may be listed that the debris flows spread from a valley into an alluvial fan so that three dimensional handling is required, that they accompany transition from the massive transport to the individual form so that it is difficult to express this process quantitatively, and that where the field observations are intended for planar expansion, the difficulty increases so that there are little field data which are reliable.

Thus, presently, the dynamical studies are scarcely concerned with models expressing the flow correctly but largely with slide models of a simple point mass or a mass of a finite size and are far apart from the actual condition of debris flows.

The simplest material point mass model is that which Okuda¹³⁾ applied to the debris flow deceleration region in the lower reach of Kamikamihori Valley of Mt. Yakedake. He expressed the flow velocity V and running distance x of a point mass coming to a slope of the slope angle θ , frictional coefficient μ and drag coefficient k (assuming a drag being proportional to the square of velocity) at an initial velocity V_0 by the formula

$$x = \frac{1}{2k} \log_e \frac{kV_0^2 + A}{kV^2 + A}$$

where $A \equiv (\mu \cos \theta - \sin \theta) g$.

The values of observation of x versus V gave the curves shown in Fig. 7. As seen, the model was simple and primitive, but the aspect of deceleration was fairly well expressed, and there were obtained the values of about $\mu = 0.085$ and $k = 0.0005/m$.

However, these values are inherent to this particular valley and the observed debris flows and have no universality and are applicable only to the situations where the boulders at the leading part of debris flow are not much spread in the alluvial fan.

12) S. Okuda. Elastic Collision of Large Stones in Debris Flow, (in Japanese), Report on Debris Flow Survey (1978). Published by Matsumoto Sabo (in press).

13) S. Okuda; On the Relation between Debris Flow Speed and Run-out Distance at Valley Kamikami, (in Japanese) Report on Debris Flow Survey (1973) published by Matsumoto Sabo.

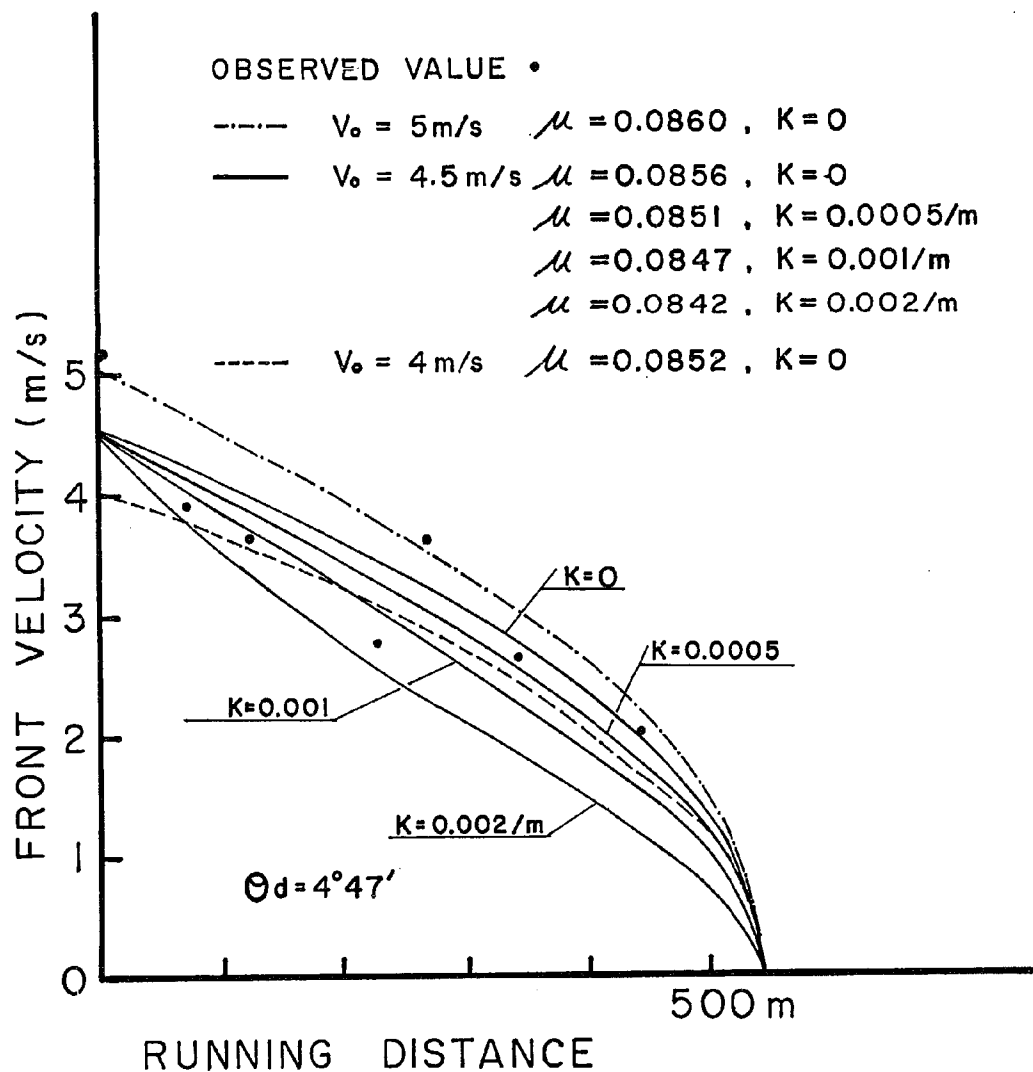


Fig. 7 Relation between front velocity of debris flow and running distance
observed at the lowest region of Valley Kamikami.
(after S. Okuda, et al ¹³⁾)

In the case of a finite size mass model there were analyses by H. Kikkawa et al.¹⁴⁾ and K. Yamaguchi et al.¹⁵⁾ Their formulas had, naturally, to include parameters concerning the shape and physical property of the flowing mass. Here, it is difficult to check up these parameters comparing with the sample observed at the sites.

For the research handling the flowing form directly, there is a hydraulic work of Tsubaki et al.¹⁶⁾ which is concerned, although not directly with the process of deceleration and stop of debris flows, but with the process of deposition in a gentle slope region. They confirmed, through calculations and experiments, that the rapid deposition was apt to occur at a place having a highest rate of change in the slope of stream bed, as shown in Fig. 8.

In the Ministry of Construction, hydraulic experiments were carried out by S. Tabata et al.,¹⁷⁾ and it was found that the deceleration and stop of debris flows would be promoted by reducing the slope and extending the width of water channel. However, it is difficult to be explained exactly by an analytical theory.

The movement of debris flows in alluvial fans is deeply connected with the human life, yet the research in this stage is most retarded. It is, therefore, urgently required to clarify the problems through theoretical analyses, hydraulic model experiments as well as field observations.

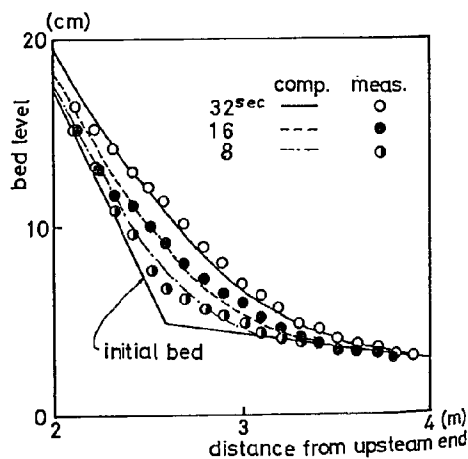


Fig. 8 Comparison between computed (lines) and measured (circles) values of bed level change in the model experiment of valley mouth with debris flow deposit. (after T. Tsubaki, et al.¹⁶⁾)

- 14) H. Kikkawa et al; On the Run-out Distance of Sliding Debris, (in Japanese) Report on Natural Disasters at Pref. Chiba caused by Typhoon No. 25 in 1972 (1972) P. 17
- 15) K. Yamaguchi; Soil Mechanical Survey on Slope Failure, (in Japanese), Report on Natural Disasters at Pref. Chiba caused by Typhoon No. 25 in 1972 p. 24
- 16) T. Tsubaki et al; On the Piling Process of Debris Flow, (in Japanese), Lecture Print on a symposium of Natural Disasters, 10th, (1973). P. 153.
- 17) S. Tabata et al; Study on Mud-flow Deposition, owing to Changes of River-width or Slopes (in Japanese), Shin-Sabo, Vol. 25 No. 2 (1972). P. 25

Mobility of Pyroclastic Flows

Pyroclastic flows have often occurred in our country at many volcanos. For example, in 1973, a small scale pyroclastic flows (Nuées Ardents in the strict sense) were observed during the eruptions of Asama volcano and were recorded by Cine Films¹⁾. Many scientific surveys on the pyroclastic flows have been carried out from a geological viewpoint, but few from a dynamical viewpoint.

Dynamical behaviour of pyroclastic flows will be briefly introduced here with the aid of recent scientific papers.

High mobility of pyroclastic flows can be explained by the gas cushion effect which supports gravels and sands in a fluidized state with strong upward gas pressure gradient and turbulent flow. This is its most characteristic point. It is different from debris flow in which voids in the debris are saturated with water mobilizing a mixture of solid particles.

A.E. Scheidegger²⁾ derived the relation between pore velocity of gas (V) and suspended particle's diameter (d) from his physical law for the flow through porous media:

$$V^{1.84} = \left(\frac{P p_g}{\eta} \right)^{0.16} \frac{2(1-P)(p_p - p_g)g}{94P^2 p_g} d^{1.16} \quad (\text{in C.G.S. units}),$$

where P is porosity, p_p particle density, p_g gas density, η viscosity of gas, and g is gravitational acceleration.

Using appropriate values for these physical quantities, he showed from numerical estimation that a Nuée Ardent of 1000 m in length, 100 m in thickness, and with a speed of 50 m/sec, can support the clouds of solid particles of 1 cm in diameter maintaining a fluidized state, on the assumption that hot particles heat up the cold air captured into the clouds, and upward airflow is produced with rapid volume expansion of the air by a factor of 3.

A modification of the above theory has been proposed by R.L. Shreve³⁾, who advanced the hypotheses that the pyroclastic flow, in fact, develops a cushion of gas at the bottom upon which it slides. The cushion of gas consists partly of air captured into the flow and partly of gas emitted from the flowing debris.

Using Darcy's law for upward gas flow through the cloud of solid particles and the thermodynamical equation for adiabatic compression of ideal gas, and the continuity equation for steady upward gas flux, Shreve obtained the condition that the pressure gradient in the upward leaking air must be sufficient to support the loose fragments at the base of the clouds for the effect of air-layer lubrication, in the following expression, (See Fig. 1):

- 1) S. Aramaki, "Small-scale Pyroclastic Flows Generated during the Feb.-march, 1973, Eruption of Asama Volcano", (in Japanese), Volcano (Kazan), II, Vol. 18, (1973), No. 2, p. 79.
- 2) A.E. Scheidegger; Theoretical Geomorphology, 2nd ed. Verlag Springer, p. 401.
- 3) R.L. Shreve; Leakage and Fluidization in Air-Layer Lubricated Avalanches, Bull. Geolog. Soc. Amer. 79, (1968), p. 653.

$$\frac{k_b \sigma_b}{k_h \sigma_a} \leq \frac{1}{m} \left[\frac{1 - (P_t/P_b)^m}{1 - (P_t/P_b)} \right] - \frac{\mu_b S^2}{p_b K (P_b - P_t)}$$

where k_b is permeability at the bottom surface of the debris layer, k_h the harmonic mean of local permeability k , σ_b the bulk density at the bottom, σ_a the arithmetic mean of local bulk density σ in thermodynamical parameter $m = (\gamma + 3)/2$, γ the ratio of heat capacities of air at constant pressure and at constant volume (≈ 1.4), P_t air pressure at the top of the debris layer (≈ 1 atm), P_b air pressure at the bottom, μ_b viscosity of air in the lubricating layer at the bottom, s thickness of the debris layer, p_b density of air in the bottom, K a parameter expressing the effect of gas emission defined as:

$$K \equiv S^2 / \int_0^s \frac{1}{k(\alpha)} \left[\int_0^\alpha E(\beta) d\beta \right] d\alpha$$

and E is the local mass rate of gas emission per unit bulk volume in the debris.

The pressure of air captured in the lubricating layer under the debris layer, its temperature (rising by adiabatic compression even without hot particles), and its viscosity (increasing with temperature rise), are shown in Fig. 2, respectively, as a function of thickness of the supported debris layer. The curves show that the thicker the cloud layer of debris, the larger the bottom pressure to support the cloud and the higher the temperature of air at the bottom.

The maximum ratio of $k_b \sigma_b / k_h \sigma_a$ (i.e. the right side of the above equation without the second term, neglecting the effect of gas emission) is shown in Fig. 3 as a function of the thickness of the debris layer. From this result, it is found that the lubricating air cushion can be dynamically stable when the product of permeability and bulk density of debris at the base ($k_b \sigma_b$) is much smaller than that averaged over the whole layer ($k_h \sigma_a$).

This stable condition for the air cushion was probably present in special types of landslide, according to Shreve, but has not yet been confirmed in many pyroclastic flows. The theoretical evaluation of friction coefficient at ground surface of debris cloud with air cushion is an important problem to be solved in near future.

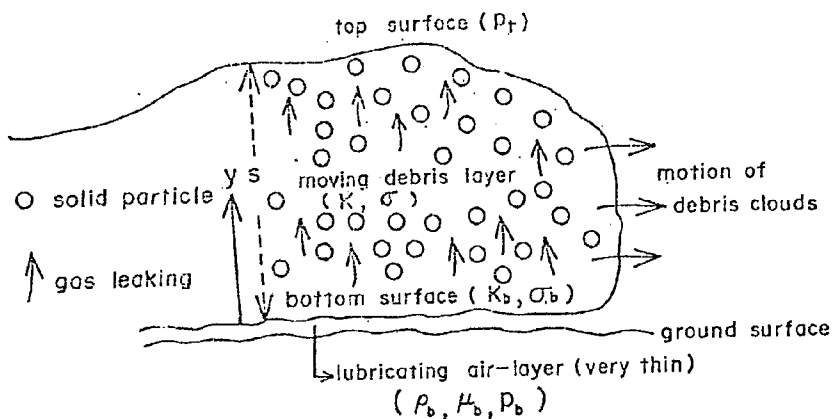


Fig. 1 Model of moving debris clouds
(by the author)

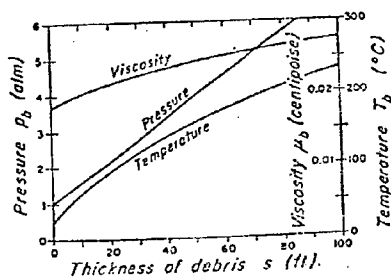


Fig. 2 Pressure, temperature, and viscosity of air in lubricating layer as functions of thickness of supported debris layer.

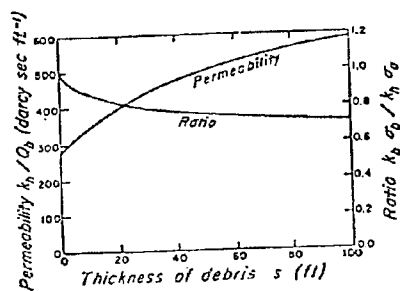


Fig. 3 Harmonic mean permeability for unit leakage rate and maximum ratio $k_b \sigma_b / k_h \sigma_a$ for air-layer lubrication as functions of thickness of debris layer. Ratio approaches asymptotic value of 0.64 as thickness increases.

(after R.L. SHREVE³)

2-2. Special Lecture

**Countermeasure Planning on Volcanic
Debris Flow around Mt. Merapi**

Dr. Aritsune TAKEI

(Prof., Kyoto Univ.)

There are many trouble problems for considering on the countermeasure against volcanic debris flow in Mt. Merapi region, because she has been erupted every 3 ~ 5 years and originating a vast movable materials.

Especially, Nuée Ardente or Nuée Ardente dávalanche is one of the very things of volcanic activity, then, a direct opposition against this is beyond human power at this stage of technology. Anyway, we should put the problem into establishment of the system for forecasting, warning and refuge.

Another problem is caused by the balance between the supply of movable volcanic debris at the source region and re-transfer to lower reaches. Essentially, the problem should be explained by quantitative and dynamic analysis backed up with long turn field survey. But, I wish to consider the problem from the viewpoint of a static balance between traveling and resisting force at this stage of topography, because lack of available information. I am expecting that we'll be able to complement the result by a progress of our joint studies.

The first stage of operation is classification of region, or zoning based on dominant active force. Fig. 1 shows the cross section of Mt. Merapi, plotted on semi logarithmic paper. The sections are taken at lines connecting the summit of volcano to Klaten, Prambanan, Yogyakarta, Salam and Muntilan. They are corresponding approximate to the direction of K. Woro, K. Gendol, K. Boyong, K. Krasak and K. Putih, respectively.

The cross sections are composed of broken straight lines and neutralize curves connecting straight lines, as is obvious from the figure. The gradient of these straight lines are nearly the same. The fact that the logarithm of elevation z is in proportion to the horizontal distance x from summit, means that, the slope gradient $\partial z/\partial x$ at any time is in proportion to elevation z , and also the erosion rate $\partial z/\partial t$ is in proportion to slope gradient $\partial z/\partial x$ at the time. Namely, the difference of gradient of straight line between upmost region and middle-down stream is explained by the difference of erosive force, dominating the movement of debris in each region. In this figure river levels and summit levels are stated also, for upper region above middle reaches, because unignorable difference between original topographic surface and eroded channel levels.

From this figure, we can presume that, upper region above 1200 ~ 1300 m is dominated by gravity force, and materials are transferred by the forms of sliding and falling, and lower region is dominated by traveling force by running water. These two region are intermediated by neutral zone, which is locating between 2000 ~ 700 m in eastern slope, and 1800 ~ 900 m in western slope. This region constitutes a debris depositing area at the foot of gravity zone, and also a temporary storage area of unstable materials at the headward of valley. An natural phenomenon originated from top of volcano is supposed to be stopped once at this area in almost case, and once deposited material will be in motion at another opportunity, by another driving force. It must be an exceptional case that materials originated from volcanic activity are transported, directly to lower region penetrating through this neutral zone. Since, the contribution of such a large scale Nuée Ardente on the formation of topography is supposed to be not so large, inspite of the frightfulness as it attacks lower land directly.

Generally speaking, I can point out some distinctive situations between eastern and western slope. In eastern slope, this neutral zone is consisted of so called old Merapi body, and it is spreading wider and thicker than western slope, but is dissected severely by fluvial erosion. Consequently, the river level in the figure is extending into source region as approaching to an intersecting point of two straight lines. I suppose that the supply of movable materials originated from volcanic activity has been not so severe as western slope for a long time,

because the present topography is considered as the result of long term process in geomorphologic balance of supply and scouring. On the contrary, the supply of movable materials from side wall of valley may play a leading part for disastrous sediment yielding in recent days. In western slope, this neutral zone is developing not so widely as eastern slope, but the intersection point of two straight lines is buried deeply in present topography, and the slope of river level shows almost same tendency as summit level. Namely, the balance of material supply and scouring on summit level and on river level do not differ essentially to each other, then the formation of stream net is not stable but changeable easily by chance. Such process as subjected by fluctuating stream net supposed to be a kind of slope process in large scale. It will be more favourable to consider the problems by dividing the region into some separated spaces of proper extent, then to consider them for the stabilizing problem of stream net, as well as river improvement works.

After all, the characteristic of neutral zone in western slope is a large scale slope process, in spite of fluvial process in eastern slope. I wish to propose a tentative plan for control measure from this point of view. Namely, in eastern slope, torrent improvement works by constructing check dams and consolidation dams should be advanced into gorges which are dissecting deeply into neutral zone, as well as possible. In western slope, we'll be unable to select a construction site at the inside of neutral zone, because there is every possibility of being ignored the plane by occurrence of capture of drainage basin. The most hasted planning is how to constrict and stabilize the outlet of this neutral zone, and how to connect smoothly from outlet of the zone to fixed stream course in middle and lower reaches.

Another problems are the stage of lower reaches. In western slope, confluence points to K. Progo have fairly high altitude, and K. Progo has relatively high capacity of sediment transport, so, there are no distinct having up of river bed around these confluence points, and a tendency of falling down are seen in some place. It suggest that the sediment transported in this region should be flushed out to K. Progo as soon as possible. We may leave the sedimentation problem to the dredging in lower reach of K. Progo. In eastern slope, around the confluence points to B. Soro and K. Opak are slowing another neutral zone affected by the characteristic of lower reaches. The ceiling river (rised bed river) at down stream of K. Woro is located on this discontinuous junction. Of course, an intense supply of movable materials at upper reach of river is one of the courses of rised bed, but the river morphology in this area shows an unavoidable constitution of ceiling river. Then, the problem in this region does not rely only how to fall down the river bed, but how to stabilize the fixed river course based on an estimated proper longitudinal profile.

The general topography of Japan is in a stage of matured, and stream net is dissecting deeply into summit level. So it can not be compared with the topography of this region. But the longitudinal profile shows also an exponential curve, that is confirmed by data analysis in some rivers in Japan, and sometimes it shows a composition of broken straight line. I suppose, the basic concept of erosion control planning does not differ from Indonesia to Japan, in spite of the difference in an intensity of debris supply and geomorphologic stage of present topography.

Although, above mentioned considerations are derived from a general view of topography, more detailed examinations are necessary to an application for practical problem. I wish to leave them for another opportunity, because the examinations are progressing now by thanks to the effort of Survey team for making master plane of Mt. Merapi Project.

Next, I wish to comment on the characteristics of debris movement in this region. The movement will be classified into two category, namely, the one is debris flow and the other is sediment transport by tractive force of running water. Although, this is only a matter of common knowledge, we must make planning after due consideration on the difference of dominating rule and occurrence probability of each phenomenon. Frankly speaking, from where does debris flow take place? and how far does it flow down? what kind of phenomenon is probable? They must be fixed reasonably at first, for the basis of planning.

Although an exact judgment is very difficult because of a defficient in field survey data and incompliteness of debris flow theory, we must suppose them to the extent within the limit of the present stage of knowledge.

The critical equilibrium condition at the occurrence of debris flow will be written by next equation

$$\tan \theta_1 \leq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho} \tan \varphi \dots\dots\dots (1)$$

- where σ : specific gravity of debris
 ρ : specific gravity of water
 C_* : bulk density of debris layer in torrent bed
 θ_1 : critical inclination of torrent bed
 φ : internal friction angle of debris layer.

Eq. 1 is of the same pattern to the critical equilibrium condition of infinit slope in saturated state. For the value of σ , we have some measured values. The survey shows that σ is 2.6 ~ 2.7 for finer particles ($d < 0.074$ mm) and 2.75 ~ 2.85 for coarse particles. For the values of C_* and φ , there is no reliable data in this region. Referring to the surveyed values in Japan, C_* is within the scope of 0.45 ~ 0.60 for the deposition of torrent bed. φ is depending principally on the density C_* for such granular material as debris deposition, and the values are reflecting susceptively to the fluctuations of density. For example, in Mt. Rokkō, φ are varying 60 ~ 27°, against C_* of 0.73 ~ 0.69, and in Mt. Fuji, φ are 53 ~ 33° against C_* of 0.56 ~ 0.52. Generally speaking, the lowest value of φ may be around 20°, because looser accumulation is hardly to build up even by carefull artificial filling. And the highest value will not exceed 40°, because the natural depositions of debris are making fairly loose accumulation, from our experience.

Now, I'll try to estimate the critical equilibrium inclinations torrent bed. The estimated values are shown in table-1.

$\varphi \backslash C_*$	$\sigma = 2.65$				$\sigma = 2.80$			
	0.45	0.50	0.55	0.60	0.45	0.50	0.55	0.60
20°	9.3°	9.7°	10.3°	10.7°	8.9°	9.3°	9.9°	10.3°
25	11.8	12.4	13.1	13.6	11.3	11.8	12.1	13.1
30	14.6	15.2	16.1	16.7	13.9	14.6	15.5	16.1
35	17.5	18.2	19.3	20.0	16.7	17.5	18.6	19.3
40	20.6	21.5	22.8	23.6	19.8	20.7	21.9	22.8

Table-1

The torrent which has steeper inclination than the values shown in the table, may be assumed to be the originating region of debris flow.

In Fig. 2, the distribution of inclination angle along main cannelns in western slope of Mt. Merapi. It is seen from this figure that about 1200 m in altitude is the lowest limit of debris flow origin. Because the inclination of talus cone at the upper portion of this region is $25^\circ \sim 30^\circ$, then, it will be reasonable to assume the value of φ for natural deposition of debris as nearly the same value to that. Accordingly, there is a few possibility for taking place a debris flow at the reach of more gentle slope than 10° , as far as considering this critical equilibrium condition. In this sense, the collection of rainfall intensity record at the region above 1200 m is more important related to forecasting and warning problem, than the collection of record in lower region.

In the next place, we must examine in another critical condition of debris flow occurrence. That is, the massive movement of sediment affected by bore-like abrupt outflow. In this case, the equation will be written as follows.

$$\tan \theta_2 \leq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + 1/k)} \tan \varphi \dots \dots \dots (2)$$

where $k = h_0/a$

h_0 : depth of bore-like surface flow, which is measured perpendicular to torrent bed.

a : depth of sediment layer, that will be in motion simultaneously under the influence of bore-like surface flow.

another symbols are as same as Eq-1

Of course, there are some constraining conditions for the choice of k values, now I'll use $k = 1$ for example, that is a reasonable value in general. The estimated values are shown in table 2.

$\varphi \backslash C_*$	$\sigma = 2.65$				$\sigma = 2.80$			
	0.45	0.50	0.55	0.60	0.45	0.50	0.55	0.60
20°	5.6°	6.1°	6.5°	6.9°	6.0°	6.4°	6.9°	7.3°
25	7.2	7.8	8.3	8.8	7.6	8.2	8.8	9.3
30	8.9	9.6	10.2	10.9	9.4	10.1	10.8	11.4
35	10.7	11.6	12.3	13.1	11.4	12.2	13.0	13.8
40	12.8	13.8	14.7	15.6	13.6	14.6	15.5	16.4

Table-2

The critical inclination of torrent bed will be decreasing in a great extent as to this condition. Hereupon, many reaches located above 800 m will be defined as dangerous, with reference to Fig. 2. Since the figure is not necessarily suitable for the understanding of general trend, the longitudinal profile and inclination angle distribution along main channels are shown in Fig. 3. From table-1 and 2, it will be assumable that the critical inclination estimated by Eq-1 is around 10° , and by Eq-2 is around 6° . Then elevation of about 1200 m for former standard, and about 1000 m for later standard are given as rough boundary lines of debris flow occurrence region, referring to Fig. 3. We can find some differences between eastern and western channels. In western, since the torrent bed is merely constituted by the balance between sediment supply and erosive force, it does not show such extreme

variation of inclination as eastern channel. Contrary, in eastern, since the torrent is dissecting severely into old Merapi body, extreme fructuations are recognized, caused by the difference of charactor of bedding material resistance against erosive force.

The next problem is the situation of middle and lower reaches, lower than 800 m in altitude. In this area, sediment is transported principally by tractive force of running water. But sediment transported under the state of debris flow on lahar is flowing into this area. We hardly find the portion where debris flow will be taking place, based on above mentioned standard, except the reaches extending about 1 km length and locating between 500 ~ 550 m in K. Krasak, and K. Bebeng. In general, the inclination is falling gradually to less than 2° as far as about 400 m in elevation. The situation is shown in Fig. 4.

Now, let us estimate the critical tractive force of bed material based on Shield's formula,

$$U_*^2 c / (\sigma / \rho - 1) \cdot g \cdot D \doteq 0.05 \dots \dots \dots (3)$$

It is recognized that the Eq-3 is applicable approximately in torrent. Since $U_{*c} = g h_c I$, then if σ is 2.65 ~ 2.8, Eq-3 is derived to

$$h_c / D = (0.09 \sim 0.11) / I \doteq 0.1 / \sin \theta \dots \dots \dots (4)$$

Calculating the values of h_c / D for $\theta = 2 \sim 8^\circ$, then following table is given,

θ	2°	3°	4°	5°	6°	7°	8°
h_c / D	2.87	1.91	1.43	1.15	0.96	0.82	0.72

Table-3

Particle size of bed material in middle reach of K. Krasak is known from field survey, as $d_{50} = 1 \sim 2$ mm, $d_{90} = 30 \sim 70$ mm. If the value of D may be assumed to equal to d_{50} , the water depth of 0.4 ~ 0.6 cm is enough to transport bed materials at down reach, and the depth less than 10 cm will flush out almost every bed materials. That is, since the size of bed material is relatively fine against the steepness of river bed, the running water will be transporting materials by tractive force habitually so far as the surface flow is appearing.

In the reaches over than 6° inclination, bed material can move at the depth less than particle size. On the other side, when a bore which has the height of $h > a$ will force the bed layer to move simultaneously, based on the estimation of Eq-2. When a bore-like flow over than 15 ~ 30 cm depth, which is corresponding to several times as d_{90} of bed material, will strike the reach covering almost whole cross section, the occurrence of debris flow seems to be the most probable.

The last problem is the situation of stoppage field of debris flow. As the experience in relatively recent days, some stoppage field of debris flow are observed. They are located at around 620 ~ 650 m in altitude in K. Putih and K. Batang, and 450 ~ 500 m, 500 ~ 550 m in K. Bebeng and K. Krasak. The inclinations of these places are nearly 2.5°, except the case of K. Bebeng which has steeper inclination as 3.2°. Assuming the value of bulk density of debris as $c = 0.3 \sim 0.5$, the estimated values of internal friction angle of debris aggregation are

given as $4.5 \sim 6.0^\circ$ against 2.5° inclination, and $7 \sim 8^\circ$ against 3.2° . It is hardly possible that such low values will be observed for stable aggregation of granular material. The shearing resistance of the aggregate at the base was estimated, by assuming the depth of deposition is $0.5 \sim 1.5$ m. The result shows the values $40 \sim 110 \text{ kg/m}^2$, and $50 \sim 150 \text{ kg/m}^2$ respectively. In comparison with survey data in Japan, they show over than 500 kg/m^2 even in lower values, and exceptional lowest value is 240 kg/m^2 . Referring to hitherto researches, the yielding strength of granular liquid is in proportion to the density of granular aggregation. If the fact may be applicable in this case, the density of this aggregate is supposed to be $10 \sim 20\%$. Even in the researches on debris flow hitherto, the density of dilatant liquid is within the region over than about 30% , and in the case of Bingham body the density is more than $40 \sim 50\%$ at least. These consideration shows that the granular liquid of more low density than examined hitherto may be keeping up a stable flow in nature, and the basic study on this phenomena should be carried out in future, beside the researches on the mechanism of stoppage process of dilatant liquid has been unsolved yet.

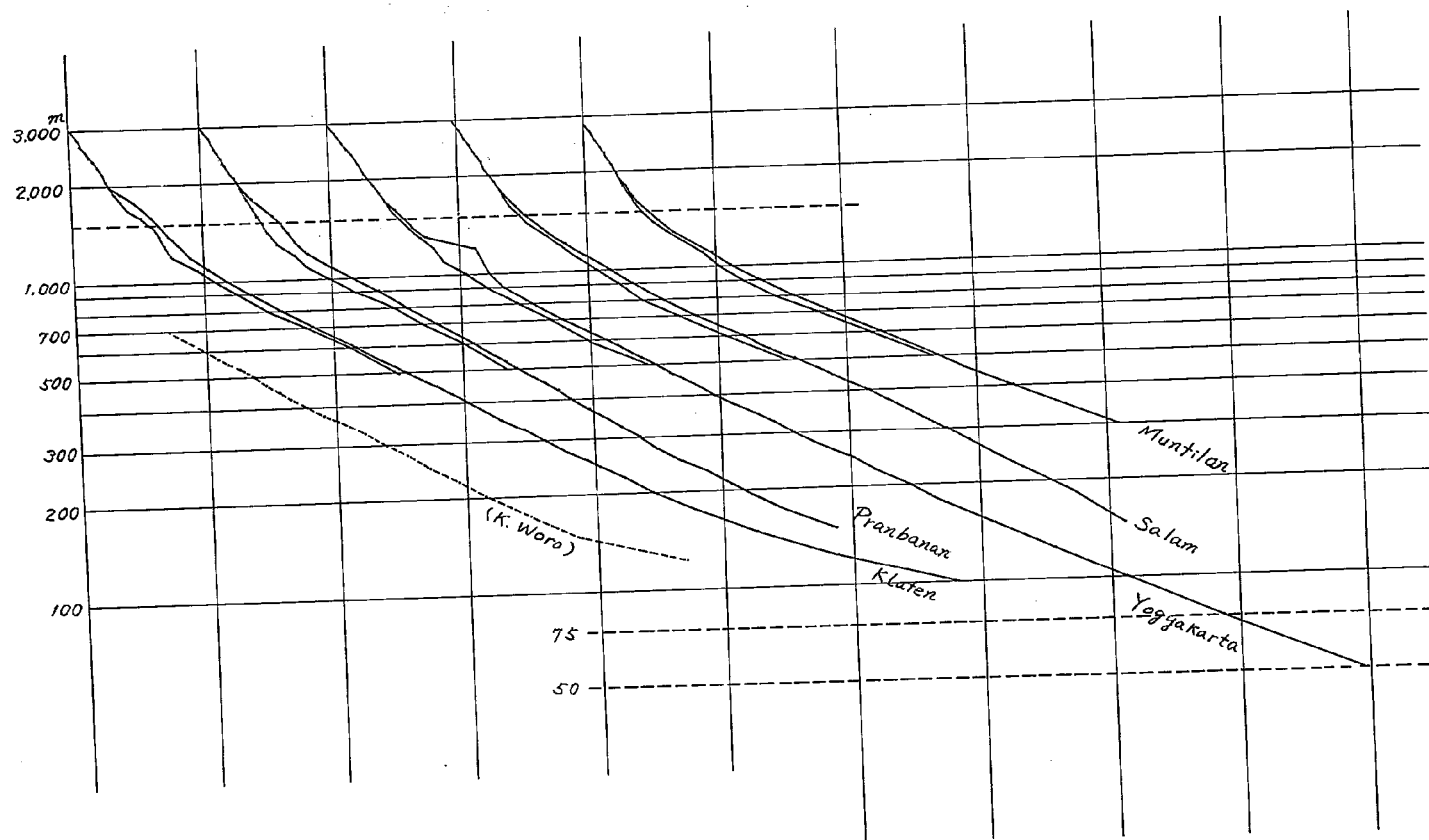


Fig. 1 Longitudinal Profiles of Rivers
(Plotted on semi-logarithmic paper)

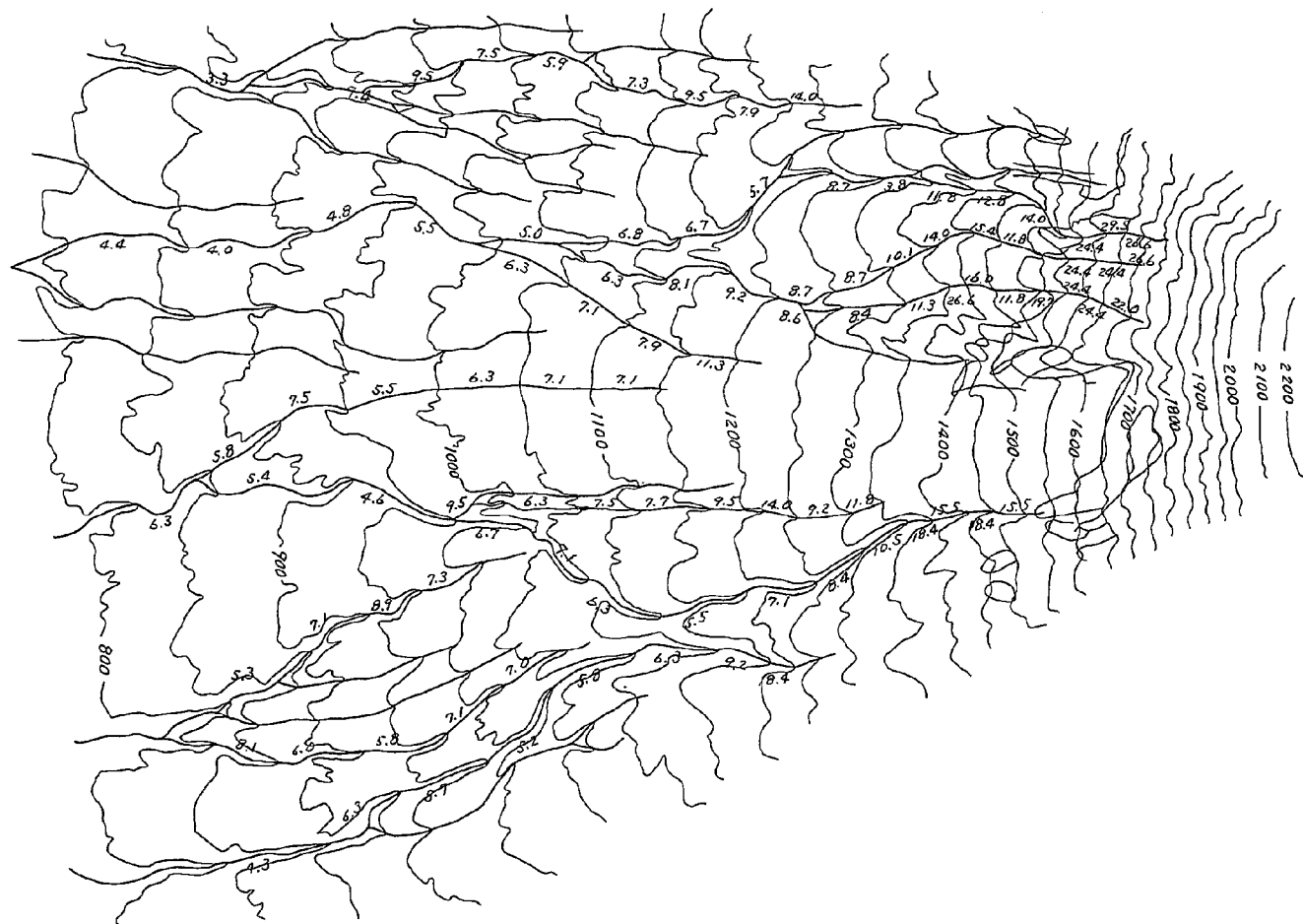


Fig. 2 Distribution of Inclination Angle Along Main Channels in Western Slope
(from K. Krasak to K. Blongkeng)

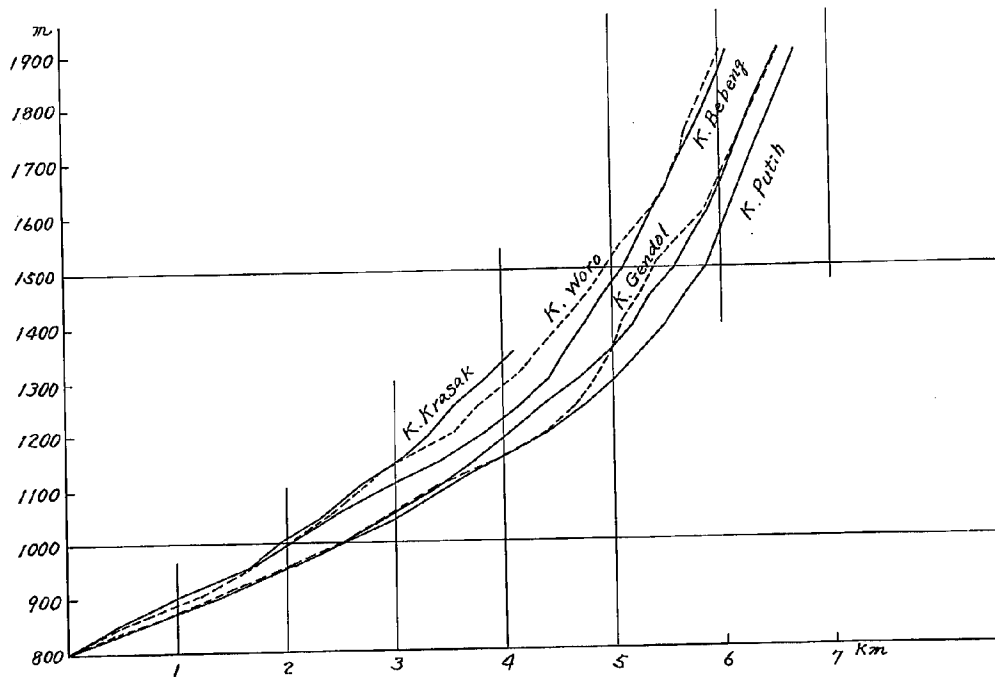
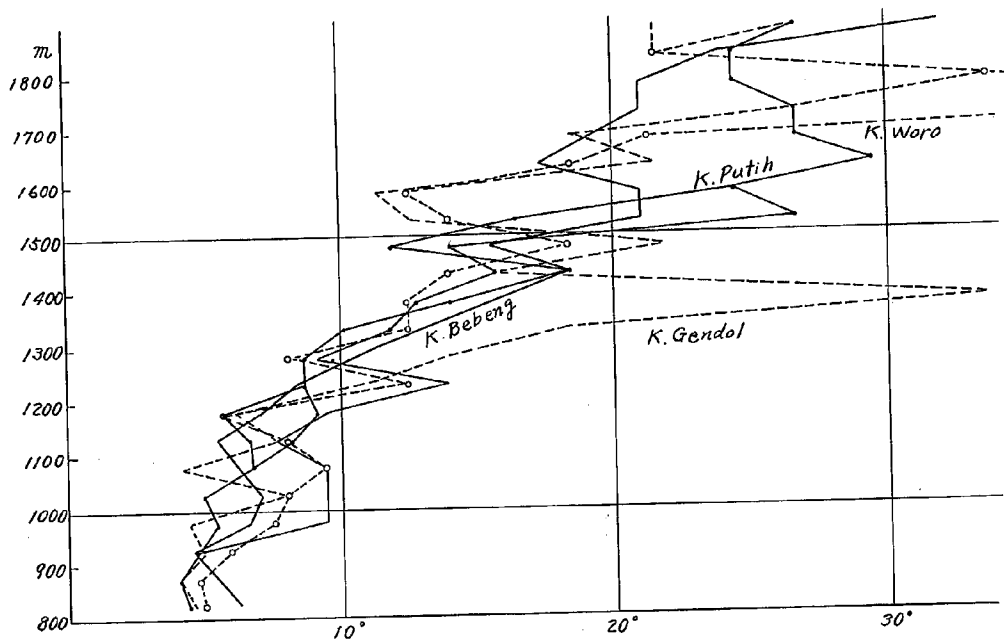


Fig. 3 Longitudinal Profiles and Inclination Angle Distribution
Along Main Torrent in Mt. Merapi

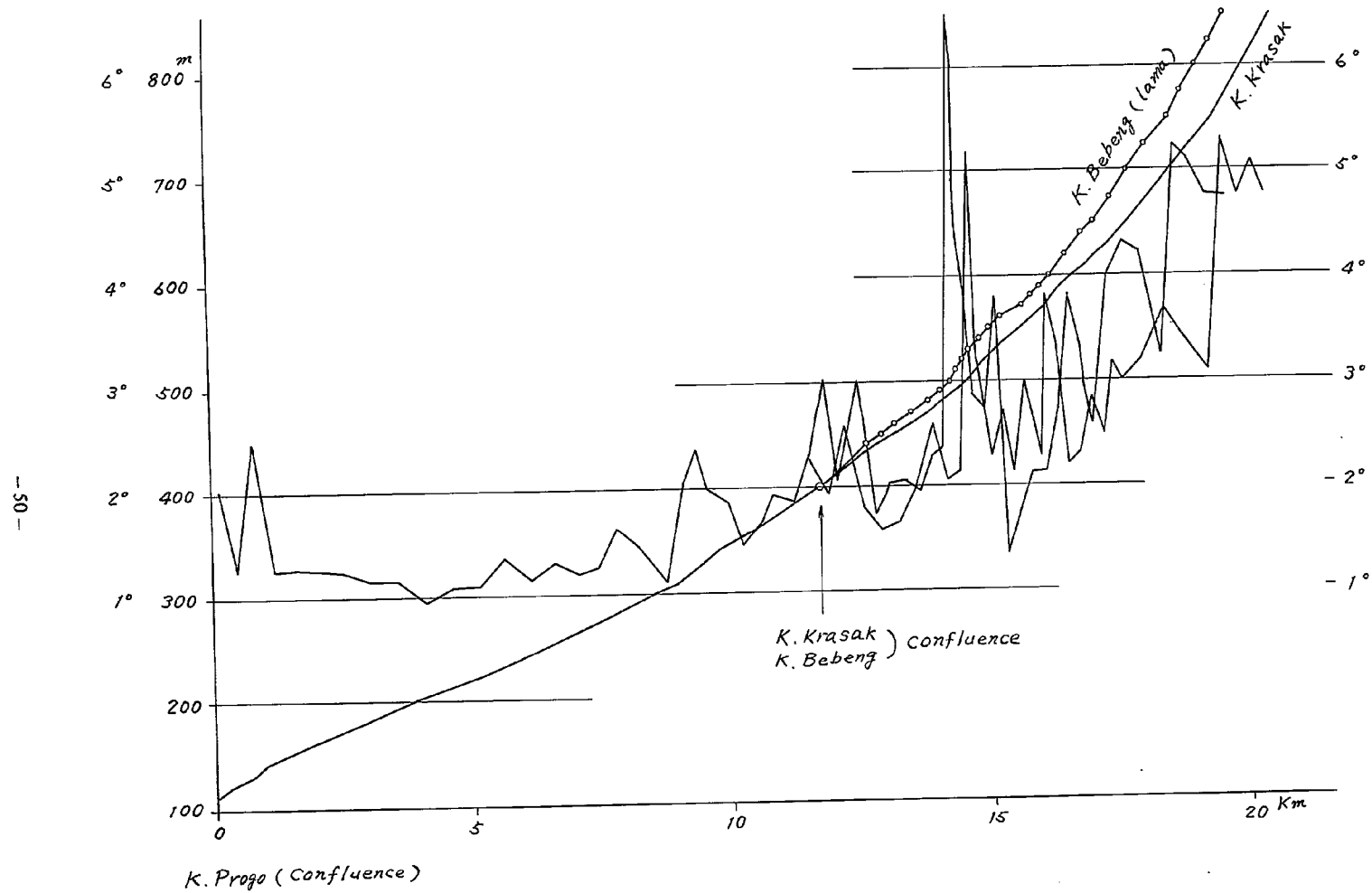


Fig. 4 Longitudinal Profile and Inclination Distribution in the Middle and Lower Reaches of K. Krasak

**2-3. Nuée Ardente at Merapi Volcano and
Precautionary Measures against
Volcanic Phenomena**

Mr. Ismangun SURYO

(Volcanology Advisor to
the Directorate of Rivers)

SUMMARY

Two types of Nuées Ardentes of the Merapi are known. The first type is the avalanche type and the second the explosion type.

These highly destructive volcanic phenomena have been for centuries menacing people living on Merapi slopes.

Yet, in spite of these dangerous volcanic phenomena, more than 40,000 people are still living in the so-called "forbidden Zone".

It is undoubtedly the fertility of the ground that they are reluctant to leave this danger area, although the Government has offered them better places to stay on other islands in Indonesia.

A map, where for each type of volcanic hazard different areas are distinguished, also called volcanic hazard map, has been made for the Merapi area.

For the purpose of safeguarding people on Merapi slopes a warning instruction is issued containing measures to be taken, before, during and after the eruption.

1. Introduction

The Merapi activity is characterized by the formation of domes of viscous lava in the crater. These domes often overflowed the crater rim and lava tongues will be formed. If these tongues continue to grow, its flanks become unstable and collapse, sending avalanches of incandescent rock fragments down the slope of the volcano. The formation of domes or tongues culminates in a series of violent eruptions, producing highly destructive *nuées ardentes*, which rush down the slope up till 12 — 13 km from the eruption point.

There are no methods of countermeasures to minimize loss of life against these powerful and dangerous volcanic phenomena. The only effective precautionary measure is to abandon completely the "Forbidden Zone", denoted on the Merapi hazard map, or to evacuate in time people still living in dangerous zones.

Afforestation of already abandoned areas in the Forbidden Zone, is probably a method to hamper the development of *nuées ardentes*, which are overflowing ravines at curves. Thus, reducing the possibility of more devastation to areas situating on the border of the Forbidden Zone.

2. Nuée Ardente, a destructive element

Nuées ardentes are the most dangerous volcanic phenomena known up to now, because of its high temperature, high speed and destructive effect. There are several types of *nuées ardentes* known, which vary according to the mechanism of the eruption. These *nuées ardentes* consist of ash, sand, lava blocks in incandescent form enveloped by extremely hot and quick expanding gases as a result of auto explosion.

According to BULLARD: Nuée ardente is a highly heated gas so charged with incandescent ash particles that it resembles a mobile emulsion yet dense enough to maintain contact with the surface as it rushes down the slope of the mountain with hurricane force. NEUMANN VAN PADANG, who was observing the Merapi eruption in 1930, defines as follows: A nuée ardente is an avalanche of heavy lava blocks rich in gases, which rushes down the slopes of a volcano. During this event the blocks are pulverized and the gases escape explosively, causing death and destruction in its surroundings.

3. Nuées ardentes of the Merapi volcano

Two types of *nuées ardentes* have been observed at Merapi. The first type is the avalanche type, caused by the action of gravity upon labile situating lava domes or lava tongues. The second type is the explosion type and is caused by the ejection of lava out of the crater.

3.1. Nuées ardentes of the avalanche type.

During an active stage of the Merapi, viscous lava may flow over the crater rim and forms a lava tongue. Parts of the unstable situating lava mass may collapse and red hot lava blocks will roll down the slope, bursting into numerous lava fragments. The glow of these red hot blocks is hardly visible at day time, but at night these lava fragments form a real fire work. They are partially turned into glowing sand and ash, forming a suspension of glowing particles in hot air, which moves down as a cloud of high specific gravity. VAN BEMMELLEN is of the opinion that blocks of about 100 m³ does not cause *nuées ardentes*, but only common avalanches of lava blocks. The development of smoke and dust of such avalanches is small. If thousands or more cubic meters of lava break

off, the development of heat and pulverized lava is so great, that the avalanche assumes the appearance of a rapidly expanding nuée ardente. The incandescent flow of volcanic debris is called with the Indonesian word ladu, while the accompanying lighter fraction, consisting of hot air, volcanic gases, sand and dust is called nuée ardente. The ladu follows the curves of the valleys, but the nuée ardente may shoot forwards at the curves and spread over the adjacent area. Such nuées ardentes of the avalanche type at Merapi commonly reach the distance of 1 – 3 km. from the crater, but big avalanches may reach the maximum distance of 7 km.

3.2 Nuées ardentes of the explosion type

During explosions lava masses may be emitted from the eruption vent. The lava is thrown up and a part of it flows over the crater rim and rushes down the slope. It develops soon into flows of incandescent debris with accompanying nuées ardentes.

The distances attained by these kind of nuées ardentes varies. They are usually short. During small explosions the nuées ardentes of the explosion type do not even reach the forest border. If big explosion occurred and big quantities of lava material are ejected, the nuées ardentes may pass the forest border. Only during paroxysmal stage of the eruption big nuées ardentes occur, rushing down with great speed and attaining distances up to 10 km or more from the explosion point. Nuées ardentes of the explosion type during paroxysmal stage of the Merapi reached 12 km in the year 1930, 12,5 km in 1961 and 13 km in 1969.

The difference between these nuées ardentes and the nuées ardentes of the avalanche type is that the first mentioned type is always accompanied by an upward rising cauliflower cloud of volcanic ashes. This cloud rises upward from the crater, and at the same time a nuée ardente rushes down the slope of the volcano.

3.3 Ladu of Merapi

About the ladu of Merapi after the eruption of 1931 Dr. HARTMANN wrote among others the following: A greater part of the gases disappeared directly after the descending of the nuée ardente. Within a short time the upper part of the red hot material are cemented together and forms typical ladu crusts. Fig. 1 shows a schematic cross section of a ladu.

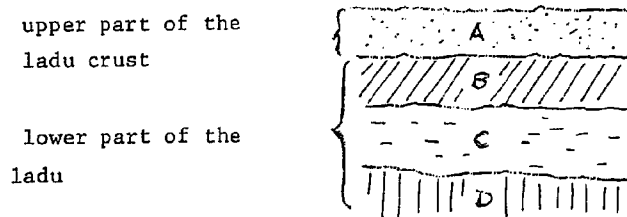


Fig. 1.

- A: Hard, grey, fine sand and clay mass.
- B: Layer in between, consisting of sulphur, partially melted by increase of temperature
- C: Course grained ladu mass, saturated with water vapour
- D: Ladu mass with much gravel and stone.

From outside it consist of a course grained greyish white and brown layer, on which more or less clear erosive phenomena can be observed. Directly below are layers of fine cemented greyish brown fine sand. The upper layer (A) of the crust consists partially of clay and fine sand of the ladu material, mixed with fresh ash, the thickness varies from 1 – 10 m.m. Beneath the upper layer follows a layer of cristallized sulphur, which shows locally melting processes (B) Beneath this layer of sulphur, lies a course-grained loose, black grey sand mass saturated with water vapour and condensed water. In the upper part of this layer one can find sulphur crystals. The sand grains and stones of the layer have a yellow brown to red brown colour, caused by iron oxide. Beneath the B – C layer, which may be 1 m thick, is the ladu material rich in sand and gravel, mixed with rounded rocks and blocks. The origin of these crusts is caused by many kinds of factors. The main factor of the crust formation is the difference in temperature originated from the heat of the ladu, the cooling down by rain, humidity and air respectively. Increase of common and colloidal silicic acid, free sulphur and sulphuric acid, organic dust and humic acid, line and alluminium supports this crust formation.

Although in the ladu material much half rotten substance of vegetation is found, the precentage of organic dust and humic acid is relatively small.

The increase of thickness of the upper crust layer resulted in a heat isolatinon, through which heat and gases are not able to escape. Only on some places in the vinicity of rocks, gases and vapour escape and caused secondary solfataras and fumaroles.

The ladu crusts prevent the penetration of rainwater in the ladu material. These ladu crusts occur only at places with high temperature, where accumulation of fresh lava material is found.

The smell of ladu is specific. It has an odour which is difficult to describe, but it reminds of rotten vegetation.

3.4. Temperatures of ladu and nuées ardentes

It is generally excepted that the temperature of nuées ardentes at the place of emission is about 1000°C, but up to now, no exact measurements on the temperature of nuées ardentes have been done. From observations at Merapi and Agung volcano, we may conclude that the temperatures of nuées ardentes of these two volcanoes differ from each other.

HARTMANN'S conclusion of the 1930 Merapi ladu is as follows:

COS gas which comes into being in the hot Merapi ladu indicates that the temperatures in the ladu must be about 450°C.

The formation of COS he said gives us the possibility of concluding the probable temperature during eruption.

As is already known COS cannot occur below 400°C. Further is also known that the inflamings point of wood is about 450°C. During the movement of ladus downstreams only a few houses or trees on the river side have been destroyed by fire. From these two facts he concluded that the ladu temperature during the eruption must be between 400°C and 450°C.

Observations during the Agung eruption in 1963 indicates that the temperature of the Agung nuées ardentes are higher than the nuées ardentes of the Merapi. After the second paroxism of the Agung volcano on May 16, 1963 the end of the ladu which followed the river of Krekuk at a distance of 1 1/2 km from the summit was still 360°C, 14 hours after deposition.

A tree trunk on the ladu was still in flame which indicate that the temperature during the eruption was above 450°C. During inspections after the first paroxysm of Agung, which occurred on March 17, 1963 we have found a house situated on the river side of Langon river, 5,5 km from the summit, that was destroyed. A glass had been found soften. From this phenomena we may conclude that the temperature of the nuée ardente might be about 700°C.

As is already explained in chapter 3.3. the crust of the ladu may isolate heat. From observations on Merapi ladus we have noticed that heat can be preserved for months. Table 1 shows that the heat of the ladu in the Lamat river in 1931 was nearly constant during 8 months.

Table 1. Temperature of the Lamat ladu in 1931

Month	Temperatures in degrees centigrade
January	97 – 100
March	95 – 96
May	98 – 104
June	55 – 100
July	40 – 98
August	45 – 83
September	39 – 95

3.5. Velocities of nuées ardentes

The velocity of nuées ardentes of the avalanche type varies. Velocities from 40 – 70 km per hour are observed frequently, but in some cases if big blocks of lava rushed down the slope, the nuées ardentes may reach the velocity of 100 to 125 km per hour.

VAN BEMMELLEN, who had observed the Merapi activity in 1942 said that blocks of lava jumped and rolled in front of the nuée ardente, with higher velocity than the nuée ardente. Further he said that the velocity of small nuées ardentes is only half of the velocity of the avalanches, while the large nuées ardentes attain the same velocity as the avalanches. These nuées ardentes are simply gravity phenomena and have therefore no initial velocity.

The explosion nuée ardente which occurred during the main phase of the Merapi eruption cycle, have a higher velocity. Velocity of more than 140 km per hour have been recorded. Observation on Mt. Agung during the 1963 eruption showed that the nuées ardentes of the explosion type attained velocities of 60–70 km per hour. Only during paroxysmal stage the nuées ardentes of this attain velocities of more than 100 km per hour.

3.6 Devastations by nuées ardentes

The destruction is caused by the ladu material the gases and the strong wind. Nearly all the trees will be uprooted if a nuée ardente passes. The vegetation along the ridges, along the ravin sides and on the stretches opposite the curve of the ravines are totally destroyed. The uprooted trees are laid down parallel to each other in

the direction opposite of the blast. Trees that remain standing is stripped of leaves and branches, the bark is stripped away on the side toward the volcano. Houses are knocked down and people are killed within a few seconds. People, who are staying not far from the destroyed area may still flee, but not long afterwards they died, apparently by dehydration. Usually a sharp boarder is noticed between the destroyed area and the scorched area. In the scorched area the trees are left upright, the leaves and the branches becomes dry by the heat and turn into a brown colour.

Table 2. Casualties and loss of properties caused by nuées ardentes
during major eruptions of Merapi volcano since 1822 through 1969.

No.	Activity		Casualties		Destroyed Villages		Destroyed houses	Heads of cattle killed	Arable land destroyed/ damage(ha)	Estates destroyed/ damage(ha)	Forest destroyed/ damage(ha)	Remarks
	Year	Date	Killed	Injured	Compl.	Partly						
1.	1822	Dec, 27-30	100	many	4		*					Coffee trees tobacco plantation.
2.	1832	Dec, 25	32	*								
3.	1849	Sept, 14-15	*	*	*		800			250.000		
4.	1872	April, 15-20	200	*	3	8	*		great	2.400 ha.	great	
5.	1888	Sept, 22			1				18 ha	great		
6.	1904	Jan, 30	16	45	3		*					
7.	1920	Oct, 12	35	*	1			13	70			
8.	1930	Dec, 18	1369	*	13	29	1109	2140	great	great	great	
9.	1954	Jan, 18	64	57	2	1	144	59	1.597		250	
10.	1961	May, 8	6		8	2	*		*			
11.	1969	Jan, 8	1			2	*		*			

*. = no record.

Table 2. shows the casualties and loss of properties caused by nuées ardentes during major eruptions of Merapi since 1822 through 1969.

4. VOLCANIC HAZARD MAPS

To guide towards the correct direction and right places of evacuation, danger maps which are actually based on volcanological history of eruptions, the eruption character of the volcano and its morphology are needed. In these so called "Volcanic hazard maps", the dangerous areas are distinctly indicated in case of an eruption and also the safe ways for the evacuation of the local population and in which the safe situating evacuation areas are already denoted.

Primary hazards are due to material directly erupted during increased activity, e.g. lava flows, efflata's and gases. Lava flows are usually easy to avoid because it moves very slowly. Big bombs only affect the direct surrounding of the crater, which are usually uninhabited. During paroxysmal stages, loss of human lives by bombs have been recorded reaching as far as 8 km from its eruption. The bombs were still glowing and set fire to the forest and the settlements causing several victims. Danger of this kind is sometimes to be avoided by seeking shelter below or behind big trees or rocks. Secondary hazard is represented by rain lahars. This phenomena is not directly caused by volcanic activity but is due to rainfall during or after an eruption.

Experience and literature study resulting in the knowledge of the behaviour and the eruption character of a volcano, makes it possible to prepare a Volcanic Hazard Map. In such a map three zones of areas are distinguished according to the hazard induced by the eruption, namely the Forbidden zone, the First danger zone and the Second danger zone.

The forbidden zone is an area surrounding a volcano situated closest to the danger source, that is easily affected by nuées ardentes, and therefore the Forbidden zone should be permanently abandoned. The First danger zone is an area which may be dangerous during big eruptions. This area may not be affected by nuées ardentes, but during paroxysms may be struck by glowing bombs. The Second danger zone is an area situated in or close to valleys originating from the summit area, and as it has a low topography, during the rainy season it may be invaded by lahar. This zone may be eventually further divided into the Alert zone and the Abandoned zone. The First mentioned is an area situating near a topographically higher area, e.g. a hill which can provided an evacuation area in case of lahar. The second mentioned zone is an area where during lahar invasion no escape is possible.

4.1 The Merapi hazard map

The danger of the Merapi volcano is usually restricted to a certain direction only. For this reason the concentric Forbidden zone and the First danger zone are divided into radial sectors, which are bordered by rivers, having their source on the summit. If the danger is restricted to a certain sector, only this menaced sector is to be evacuated.

The following sectors have been established:

1. Kedu area

- Trising — Senowo sector
- Senowo — Lamat sector
- Lamat — Blongkeng sector
- Blongkeng — Batang sector
- Batang — Krasak sector

2. Yogyakarta area

Krasak — Boyong sector.

Boyong — Gendol sector

Gendol — Woro sector

3. Sala area

Woro — Apu sector

Apu — Trising sector.

At this moment more than 200.000 people are still living in the danger zone. Table 3 shows the areal extent of each danger zone and the number of people living in the zones concerned.

Table 3. Merapi hazard map

Forbidden zone		First danger zone		Second danger zone'	
Areal extent km ²	Population x 1000.	Areal extent km ²	Population x 100	Areal extent km ²	Population x 1000
186.4	40.8	100.8	72.6	99.6	93.2

5. THE MERAPI WARNING SYSTEM

For the purpose of safeguarding the people living on the Merapi slopes a general instruction is issued by the Governor of Central Java and Jogjakarta. In this instruction is stated that steps should be taken if:

1. Increased activity of the volcano occur
2. An eruption occur accompanied by the formation of nuées ardentes
3. Heavy rain occur which gives rise to the formation of lahars.

To warn the local Government and the population against the coming danger, walky talkies telephones, sirenes and messagers are used. A so called tong — tong (a hollowed tree trunk) is also used for this purpose.

5.1 "Beware of Merapi" warning

If an increased activity of the volcano is observed, the observer at the observation post immediately gives the warning "Beware of Merapi" to the nearest telephone office. The telephone operator in turn passes this information to officials. The district Head sent immediately a messenger to inform the Village Head about the situation. At once the Village Head warns the people by stricking the tong-tong as follows:

two times — pause — two times — pause etc.

If the activity becomes more serious, but direct danger is not yet to be expected, the observatories concerned have to warn the Local Government and the coordinating Office at Jogjakarta. This Coordinating

Office advises the Governor, whether it is necessary or not to evacuate people out of a certain manaced area (the aged, sick people, women and children). If it is possible the cattle are also taken to evacuation places.

During an active stage usually only a part of the Merapi slope is menaced by nuées ardentes and lahars so that it is not necessary to evacuate the whole population living around the volcano. To facilitate and restrict the evacuation, the danger zones are devided into radial sectors, as is explained in chapter IV. For the purpose of evacuation the Governor may ask the local military commander for assistance.

5.2. Warning against big nuées ardentes and strong eruptions

Nuées ardentes are called big if it exceed the border of the forest. There is no difference between nuées ardentes of the avalanche type and nuées ardentes of the eruption type. Because both are equally danger for both kinds of phenomena, therefore there is only one signal namely the signal 'Beware of nuées ardentes'.

The observation post Babadan gives the signal for the West sector, the observation post Plawangan for the south sector, Deles for the East sector and Jrakah for the North sector.

The tong-tong should be stricken as follows:

4 times — pause — 4 times — pause etc., and if necessary the signal "run" by means of continuously striking of the tong-tong without pause. Continuously striking of the tong-tong should also be executed during strong eruptions by all of the observation posts. Also hand sirenes should be used for the "run" signal by turning the handle of the instrument fast and slow alternately.

At the moment the population hears the sign "ready to run" the people in the field have to hasten to their houses and be ready to evacuate. Old and sick people, children and women in the Forbidden and First danger zone have to evacuate at once and moved to the already assigned evacuation place.

At the moment the sign "run" is heard, the population in the area to be abandoned, at once have to evacuate without taking anything with them, except some necessary things e.g. among others food for three days, legitimation card and at night a torch or flashlight. The evacuees have to go straight to the already denoted evacuation places.

5.3 The end of the alarm

If the situation is not dangerous anymore, the Governor after consulting with the Head of the Volcanological Survey may cancel certain measures. Canceling the signal "Beware of Merapi" and "evacuate" is done by the District Head. If the community has already evacuated, the civil authorities should allow the people to go back to their villages.

5.4. Lahar and flood warning

The instructions for the lahar warning will be explained in the paper "Lahars in Indonesia and counter-measures to minimize its hazard".

6. CONCLUSION

Disasters of great dimensions are produced by nuées ardentes on Merapi volcano slopes. The only method of saving life is a timely evacuation of the menaced areas. Temperature measurements of ladu and nuées ardentes during eruptions have hitherto not been made. A device is suggested to be designed for this purpose and to be

installed on the Merapi slopes. This will certainly be very useful for the designing of engineering structures to be built in areas, which may be affected by nuées ardentes.

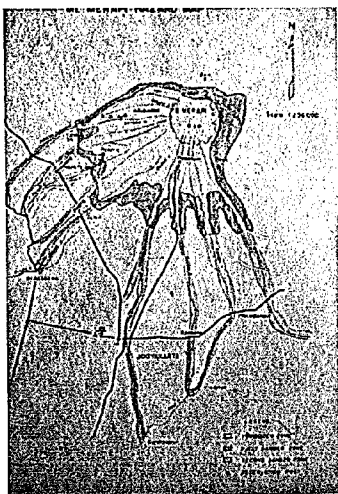
Coordinated research work for selecting the most suitable tree to be planted in the abandoned area in the Forbidden Zone should be carried out, to obtain a strong barricade against invasion of nuées ardentes.

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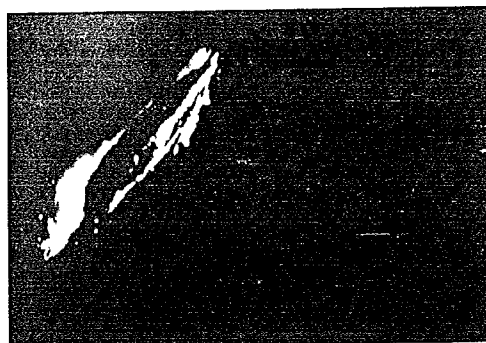
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Mr. Suryo's photographs



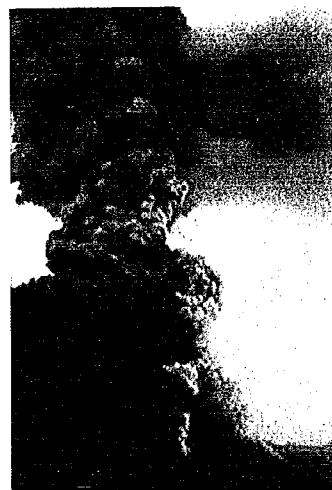
Hazard map of MERAPI



Lava Dome
(MERAPI Volcano 1976)



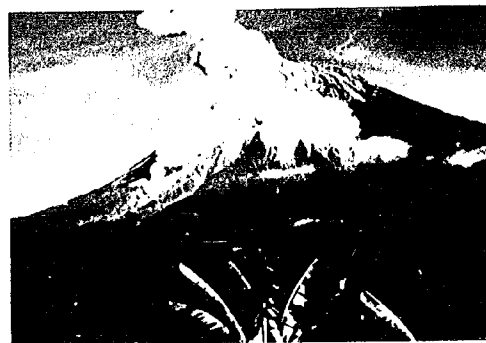
Avalanch from LAVA TONGUE
(MERAPI Volcano)



**Eruption Nuée Ardente
(MERAPI Volcano 1961)**



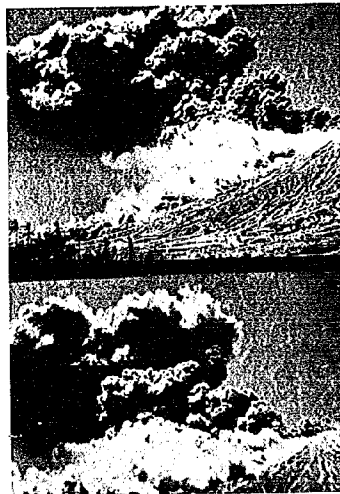
**Eruption Nuée Ardente
(MERAPI Volcano 1961)**



**Eruption type Nuée Ardente
(SEMERU Volcano 1974)**



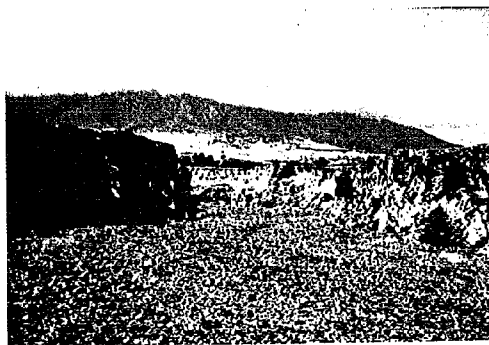
Avalanche type Nuée Ardente
(MERAPI Volcano 1968)



Eruption type Nuée Ardente
(MERPI Volcano 1961)



Devastation by Nuée Ardente d'explosion
(KELUT Volcano 1966)



Devastation by Nuée Ardente
(SEMERU Volcano Dec., 1977)



Ladu deposit of 1963. AGUNG Eruption
(Feb., 1962)



Devastation by Eruption type Nuée Ardente

**2-4. Recent Study on Volcanic Debris
Flow in Japan**

Mr. Yoshiro YOSHIOKA

(Director, Erosion Control Department
P.W.R.I.)

Recent Study on Volcanic Debris Flow in Japan

by Yoshiro YOSHIOKA

Chairmen and gentlemen, I appreciate to have a opportunity to read my paper. I will talk on 7 subject as follows:

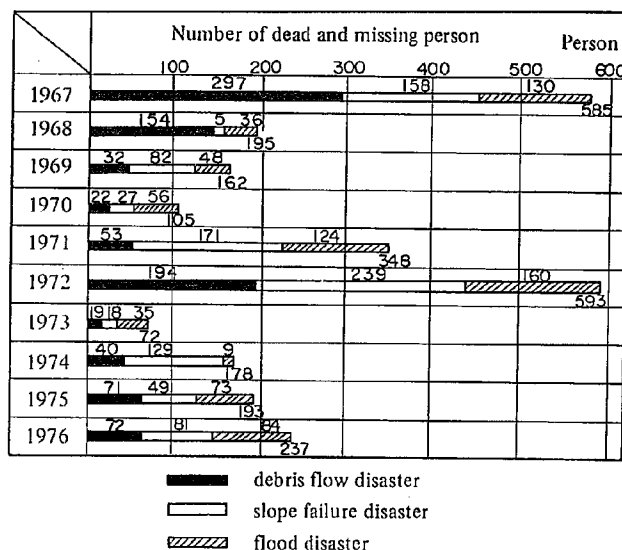
- 1) Requirement on debris flow study from administration side to research worker
- 2) Concept and the term debris flow in Japan
- 3) Circumstance on debris flow occurrence and standstill
- 4) Relation between debris flow occurrence and precipitation
- 5) Selection of dangerous torrent for debris flow
- 6) Charactor of debris flow
- 7) View on research for debris flow

I will use the advance print which is prepared for this symposium and interpreted in English. Papers written by Mr. Yamauchi or Mr. Mori in the advance print includes my view.

1. REQUIREMENTS ON DEBRIS FLOW STUDY FROM ADMINISTRATION SIDE TO RESEARCH WORKER

Disasters caused by debris flow are serious trouble to our country. Because many people lost their life suddenly with their property. Next table shows casualties in recent disasters caused by heavy rain in Japan.

Table 1. Casualties in recent heavy rain disaster
(after M. of Construction)



By the table-1, 954 person died by debris flow disaster for the past ten year. So, achievement of debris flow treatment study is expecting by administration side to adopt the debris flow countermeasure plan making. An debris flow treatment study, required theme from administration side are two problems. First is how to select dangerous torrents through the whole country, and how to put in order them. Other is how to get the reasonable check dam design method for a countermeasure work of debris flow. In summer 1977, Ministry of Construction performed a investigation to search dangerous torrent. In this case, dangerous torrent means that there are excess 5 houses in the basin which has ability of damage caused by debris flow. Consequence showed that 62,272 torrents and 1,020 thousand houses are exposed for debris flow disaster. Among them about 30% are related volcanic zone. It is difficult to achieve countermeasure those of all because torrent number is too much. So, administration side requests to find how to classify by their ability of dangerous to give successive countermeasure work. And, about a area that countermeasure work did not achieve, administration side will adopt the warning and evaluation system and the land use regulation to save inhabitants from danger in these area. To make arrangement the technical standard for warning, we have to be clear the relation rainfall density and occurrence of debris flow. Certainly, investigations and research works of debris flow is advanced in this decade. And availability of check dams as debris flow countermeasure work was proved whenever disasters happened

each place. But in present time we have a small number of data yet to make reasonable design the check dam.

Technical questions are as follows:

- (1) How to estimate a volume of debris flow as a object for plan making.
- (2) Problem of dam pocket in a field. Because dam pocket considered to be enough to accept the above mentioned planning debris flow volume. But in real field, it is difficult to find a suitable place which has above mentioned condition.
- (3) How to select the location of check dam. A geomorphological condition which can be stop or dis-accelerate a moving debris flow is have to consider but volume of dam pocket.
- (4) Reasonable structure of check dam. When a debris flow direct hit a check dam, it must have enough structure without serious damage.

2. CONCEPT AND THE TERM DEBRIS FLOW IN JAPAN

I have used the term debris flow from the start. There is a term mud flow as similler.

I will mention the relation and the distinction of two similler term to avoid the confusion of discussion here-after. I made a Fig. 1 to explain my view.

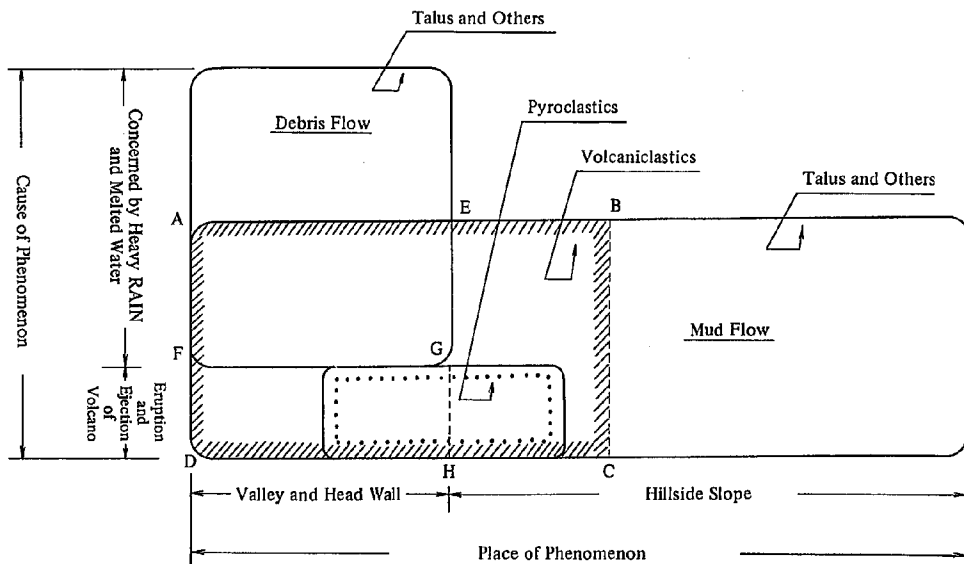


Fig. 1 Relation of Debris Flow and Mud Flow

To make Fig. 1, my viewpoints are as follows:

- (1) Place (Hillside slope, Valley and head wall)
- (2) Cause (Eruption and ejection of volcano, Occurred by rainfall and melting water)
- (3) Material (Volcanic products — Volcaniclastics, Pyroclastics, Non volcanic products — Talus, Debris and others)

In this case, mud flow has broad sence rather than debris flow. By Fig. 1, I can call a volcanic mud flow domain A B C D. Similarly, volcanic debris flow is domain A E G F. Hence, volcanic mud flow and volcanic debris flow to be same is only in case of domain A E G F. Why I use the term volcanic mud flow? Because the term volcanic debris flow is find in the scope of works of the joint study and I suppose we do not feel inconvience on the term confusion while our understand of term.

There are 195 volcanoes or volcano groups in Japan according to Geological Servey in Japan. But large majority of them are so called extinct volcanoes. At volcanic area, volcaniclastic deposits or debris get motion and change into volcanic debris flow due to action of subsurface water or surface flow. Other hand, in weathered granite area and similar characteristic rock area, occurence of debris flow is frequently. In Japan, debris flow at volcano and debris flow at weathered granite torrent are similar in their flowing shape. So, the debris flow observation stations to study the charactor of debris flow are prepared at the torrent of volcano. Because there is high frequency compared with other geological condition. I can say, in Japan we observe characters of volcanic debris flow to know the character of general debris flow. Therefore, most of data on the character of debris flow which we got already (subject 6) in this paper) are arranged from volcanic debris flow.

In Japan, the clear definition of the term debris flow is never given by society. I understood that debris flow is a phenomenon which compound flow consist of muddy materials, rocks and water descend the torrent. Debris or talus which get motion due to actions of water change into a compound object like a mass.

In recent years vigorous efforts have been devoted to the researches and studies on the mudflow and there are reported large-scale observation projects and visual recordings by use of cine cameras and video tape recorders. In former days this phenomenon was sometimes called the "mudflow the phantom", for very few people had witnessed such an avalanche actually rushing down a hillside and it was only possible to imagine what it was like by dint of a very few witness reports and inspection of the havoc caused by the mudflow in the downstream area.

Tani¹⁾ has summarized such witness reports as follows.

- (1) When seen in its cross section, an mudflow has its surface curved upward. In its longitudinal section, it raises its front as shown at right in the same figure.
- (2) An mudflow rapidly flows down, like storm clouds, sending out "smoke", clouds of spray, carrying mud, sand, rock, and trees in a hill-like mass. It is a flow of earth and rock rather than of water and has a bad smell.

1) I. TANI; Dosekiryu (Yamatsunami) ni tsuite, Suiri Kagaku, No. 60, 1968

- (3) Trees are swept downstream, turning around in the direction that the mudflow rushes on. Some trees with their roots are seen move along in the upright position.
- (4) A roaring sound like that of a thunder or airplanes flying in a formation is heard when an mudflow comes and passes by.
- (5) Before the occurrence of an mudflow, the mountain river which was rising so far suddenly begins to fall off (in the case where a natural dam is formed).

We can easily imagine what a mudflow is like and its tremendous destructive force from such fragmental hearsay information.

Pyroclastic flow disaster is not happend in recent Japan.

3. CIRCUMSTANCE ON DEBRIS FLOW OCCURRENCE AND STANDSTILL

To solve that kind of problem, research method is two ways. One is field measurement of physical elements. We are observing the moving debris flow preparing the observatory but on occurrence itself we do not attempt a field survey. Other one is to do observe the trace which a debris flow was occured and flowed. Purpose is to get data of elements about occurrence and standstill. I believe that performance of two ways are considered to be solve this problem.

From our several case of findings, they came up with the following proposals as to the criteria by which judgement is to be made for the mountain streams where there is the danger of mudflows.

1 The mountain stream bed has gradients exceeding 10° . 2 There are deposits on the bed where the gradient is 20° to 30° 3 Such deposits are unevenly distributed on the bed. 4 River-bed water is coming. 5 There is a hollow in the upstream which is likely to cause a landslide.

If a mountain stream has all the above factors, it is most dangerous while it is safest if it does not have the factors 1 and 2. It is somewhat dangerous where there are no factors 3, 4 and 5.

I hope you to read page 115 line 4th if you had a time.

About the transportation of sands or muds, to know the distinction of debris flow area and the tractional area is important question when we make a plan of check dams.

The "study on mudflow" was taken up as a subject of study at a seminar held by the Ministry of Const-
ruction in 1970. In the technological research project, it was proposed to divide the mountain stream into two types of areas, that is, the mudflow areas and the tractional areas as on of the objectives of the study.²⁾ The Erosion Control Laboratory of the Public Works Research Institute proposed the following two methods.

1 Paying attention to the largest boulders existing on the river bed, a study will be made to see if they can be moved downstream by the tractive force at the particular point. 2 A judgement will be made on the face that in the case of the transportation of earth and rock by tractive force, unlike in mudflows, the materials are once subjected to a classifying action within the range of changes occurring in the river bed during a flood with the result that the deposits on the bed will be stratified.

2) Erosion Control Division of Public Works Research Institute; Dosekiryu ni kansuru kenkyu, Report on the 26th Technological Study Meeting of M.C. 1972 and 1973.

In the method 1, we assume a tractive force U_*^2 as a force acting to transport the boulders on the river bed and a critical tractive force U_{*c}^2 as a tractive resistance. Now we consider that the particular location is a tractional area if the critical tractive force U_{*c}^2 of the boulders existing on the river bed is smaller than the tractive force U_*^2 and it is a mudflow in the reverse case.

where

$$U_*^2 = g \left(\frac{Qn}{11/2.B} \right)^{3/5} . I$$

g : Gravitational acceleration (9.8 m/sec²)

Q : 200-year probability flow rate (m³/sec)

I : River bed gradient

B : River bed width (m)

n : Coefficient of roughness

$U_{*c}^2 = 80.9 \times d_{\max}$

d : Maximum boulder diameter

2 It is often very difficult to make a judgement as to whether the deposits on the river bed have been caused by mudflow by the presence or absence of stratified formation because of the disturbances caused by the running water or other causes. The following is an outline of the investigations carried out on the Inari River within jurisdiction of the Nikko Erosion Control Construction Office with a view to understanding the structure of deposits.²⁾

(1) Form of deposits

In many cases, the mudflow deposits are affected by tractive forces after deposition so that their surface is flattened.

(2) Distribution of clay

The distribution of clay deposits was classified into the following four types.

1 Stratified distribution

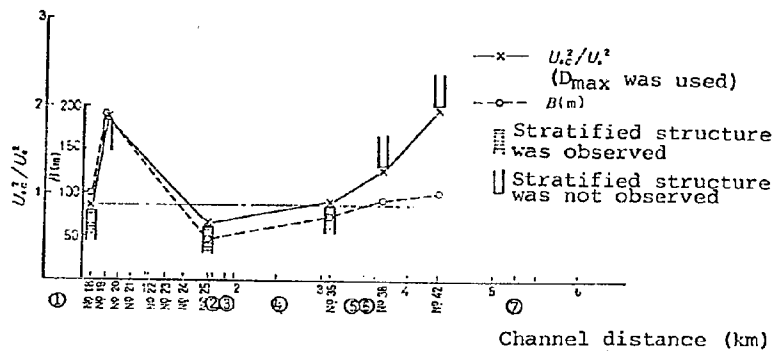
2 Interrupted distribution

3 Sticking onto boulders

4 Stratified distribution in the gaps between large boulders

Of the above, 1 and 2 are representative of the clay distributions which are observed clearly in the mudflow. In some cases, the material filling up the gaps between the boulders is generally homogeneous and muddy and obviously contains clay which is not stratified but distributed throughout the material.

Comparing the above two methods, we obtain what is shown in Fig. 2.



- | | |
|-------------------|--------------|
| ① Fudano Dam | ⑤ Nogo No.1 |
| ② Konokane Valley | ⑥ Ara Valley |
| ③ Kondo Dam | ⑦ Nogo No.2 |
| ④ Koiru Valley | |

Fig. 2 Nogo Valley of the Neo River
(after Chubu Regional Construction Bureau)

A method to make judgement as to whether the deposits on the river bed have been caused by debris flow by the presence or absence of stratified formation is mentioned in Japanese technical standard (Technical standard for river works and erosion control works published by Japan River Society) with method to search the topographical features of river bed.

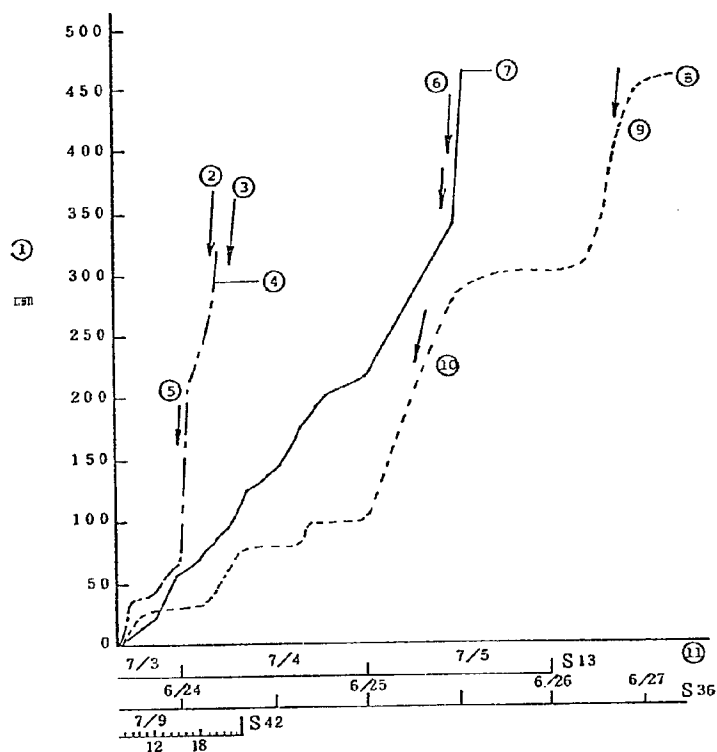
4. RELATION BETWEEN DEBRIS FLOW OCCURENCE AND PRECIPITATION AS INDUCEMENT

To know the relation between occurrence and precipitation is a necessarily to make a technical standard for warning and evacuation system.

Conventionally, the proximate causes of the sediment disaster are considered to be large accumulative rainfall and high intensity of rainfall. This may be true but, as seen in the examples of Amakusa of Kumamoto Pref. in July, 1972 and of Shigeto in Kochi Pref., the concentrated storm rainfall occurs in small area so that rain in an area 10 km away from damaged area may be completely different from that seen in the damaged area. Thus, collection of data of rainfall related to the origin of the sediment disaster is very difficult and checking of this problem has not been performed. However, more data have become available after the disaster of July, 1972, and typical examples of data of storm rainfall which caused damage will be indicated below. Data of slope breakings will be also added to the data of mudflow for indicating sufficient data.

Fig. 3 indicates three cases of slope failures occurred in the Rokko mountain system of Hyōgo Pref., and 7.1938, 6.1961, and 7.1967 indicate year and month of occurrence of disaster. 7.1938 is famous Hanshin Disaster.

For expressing the way of rainfall, time is plotted on horizontal axis and accumulative rainfall of hourly rainfall depth of each rain is plotted on vertical axis. Then, intense rainfall can be easily recognized since the slope of curve becomes very steep. In the disaster of 7.1938, accumulative rainfall was from 300 mm to 400 mm before a great number of large-scale breaks occurred, and about 5 hours is taken after the curve sharply rises, that is, after the increase of the rainfall intensity. In case of 6.1961, many natural slopes and lands prepared for houses were broken. In this case, the rain stopped for about 11 hours but heavy rains continued for 6 to 7 hours before and after the stop. In case of disaster of 7.1967, many slope breakings occurred at the end of heavy 5-hour rainfall.



- | | |
|------------------------------|-------------------|
| ① Accumulative rainfall mm | ⑦ 7. 1938 |
| ② Many breakings | ⑧ 6. 1961 |
| ③ Ichigawara slope breakings | ⑨ Secondary break |
| ④ 7. 1967 | ⑩ Primary break |
| ⑤ Small break | ⑪ Time |
| ⑥ Break | |

Fig. 3 Accumulative Rainfall of Disaster in Rokko Mountain System in Hyōgo Pref. (weathered granite area)

Fig. 5 indicates accumulative rainfall and time of mudflow occurrence of each land in the disaster of 7.192. Deep formation of plutonic rock was broken in Shigeto, Kōchi Pref., talus cone was broken and mudflow occurred in Amakusa, Kumamoto Pref., surface layer of granite was broken and mudflow occurred in Kitamikawa, Aichi Pref., granodiorite surface was broken and mudflow of talus cone occurred in Tanzawa, Kanagawa Pref., and mudflow began from landslide type break of altered andesite in Ebino, Miyazaki Pref.. Geologically and locationally different places are shown together in Fig. 6 mainly because to show that the break and mudflow occurs not only at the end of heavy rain but also at the time of heavy rain or after the stop of heavy rain. For avoiding confusion by showing too many data, now let consider only the places where geology comprizes granite, and rocks which are weathered as granite. In Fig. 4, each disaster of 7.1967 in Kure, Hiroshima Pref., 7.1973 in Dazaifu, Fukuoka Pref., and 7.1974 in Shodo-shima, Kagawa Pref. are added in addition to previously shown Rokko, Mikawa and Tanzawa. The maximum rainfall intensity was 99 mm/h for 7.1972 of Dazaifu and, for 7.1974 of Shodo-shima, 90 mm/h for Ywakadani, 92 mm/h for Taiyo-no-oka, 85 mm/h for Fukuda and 59 mm/h for Utsumi dam. It may be improper to draw general characteristics from only 11 examples in the figures, but break or mudflow occurs after continuous heavy rain (70 to 100 mm/h). And mudflow disaster occurs after accumulative rainfall of 150 mm (for instance, depth of weathered layer in Dazaifu is 20 meters in some area) but most of disasters occur when it reaches to 250 mm. And rainfalls from the time of sudden increase to start of the mudflow are also nearly same in many cases of disasters.

According to mudflow disaster report prepared by the Sabo Division of the Ministry of Construction for applying petition for emergency sabo works, 187 examples were reported. Seo and Funazaki analyzed these examples and draw the following conclusions:

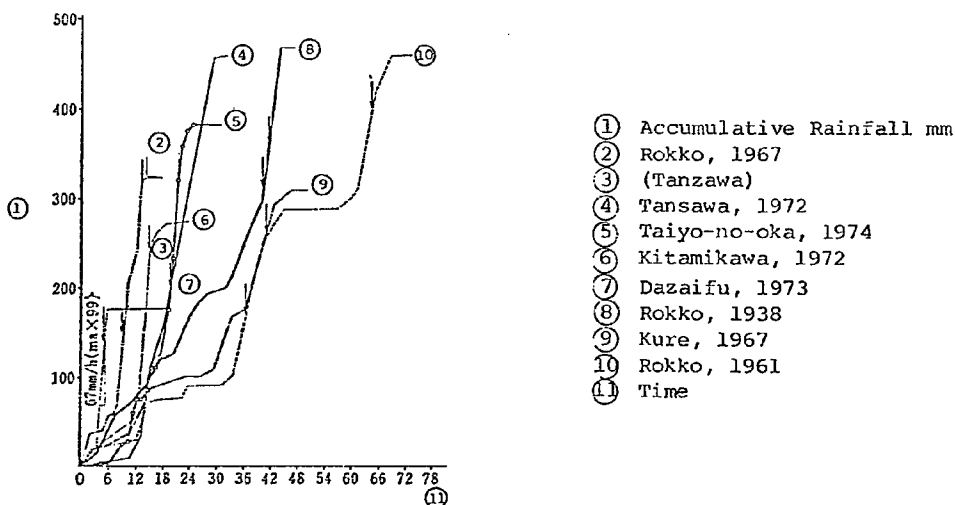
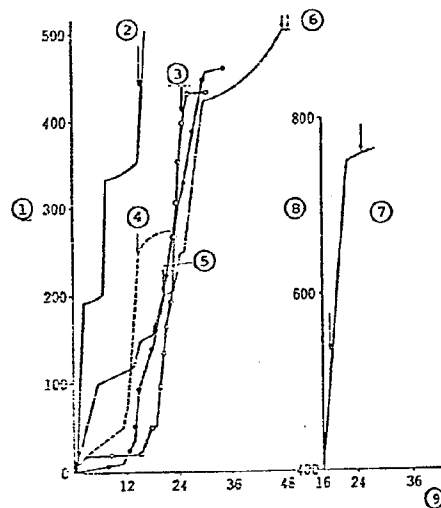


Fig. 4 Accumulative Rainfall of Valley Comprizing

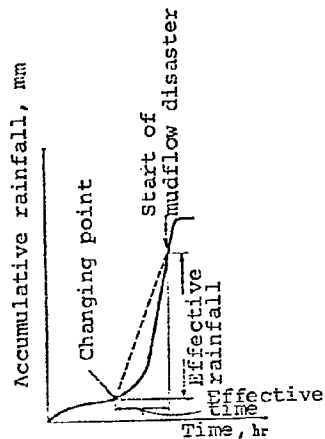


- | | |
|------------------------------|----------------------------|
| ① Accumulative Rainfall mm | ⑥ Miyazaki (Ebino) 1972 |
| ② Kōchi (Tentsubo) 1972 | ⑦ Kōchi (Tentsubo) 1972 |
| ③ Kumamoto (Takigatake) 1972 | ⑧ Accumulative Rainfall mm |
| ④ Aichi (Toyota) 1972 | ⑨ Time hr |
| ⑤ Kanagawa (Miho) 1972 | |

Fig. 5 Accumulative Rainfall of Disaster in July, 1972

As indicated in Fig. 6 (a), the accumulative rainfall from changing point where the accumulative rainfall curve suddenly rises to the time of start of sediment disaster is called "effective rainfall". And mean rainfall intensity obtained by dividing the effective rainfall by the time required for the effective rainfall, is called "effective rainfall intensity". According to the analysis, the mudflow does not occur even if the effective rainfall is high if effective rainfall intensity is lower than 4 mm/h, and disaster does not occur even if the effective rainfall is high if the effective rainfall is less than 40 mm. Relation between effective rainfall and effective rainfall intensity is shown in Fig. 6 (b) using approximate degrees of mudflow damage as parameter.

In this figure, Area I is place where mudflow damages rarely occur, Area II is place where large-scale damages hardly occur though direct attacks of broken earth may occur and Area III is place where large-scale damages occur.



(a)

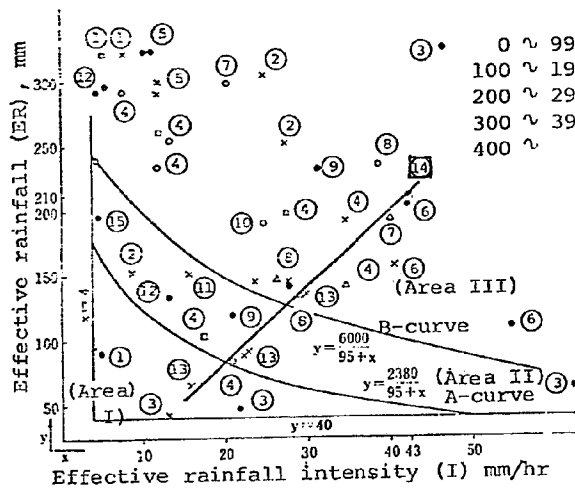
Effective rainfall intensity

$$= \frac{\text{Effective rainfall}}{\text{Effective time}}$$

Fig. 6 (a) Effective Rainfall vs. Effective Rainfall Intensity

(b)

First period rainfall amount



- ① Hiroshima
- ② Mie
- ③ Kumamoto
- ④ Kagoshima
- ⑤ Yamaguchi
- ⑥ Gifu

- ⑦ Miyazaki
- ⑧ Yamagata
- ⑨ Tokushima
- ⑩ Kanagawa
- ⑪ Tochigi

- ⑫ Ehime
- ⑬ Kagawa
- ⑭ Shodosima in Kagawa
- ⑮ Aichi

Fig. 6 (b) Effective Rainfall and Effective Rainfall Intensity vs. Degrees of Disasters
(Original figure is made by Seo et al.)

4 data in Kagawa Pref. are plotted in this figure, and they are on a straight line when connected. If effective rainfall of 210 mm, effective rainfall intensity of 42 mm/h and first period rainfall amount in 2 weeks of about 150 mm in 7.1974 in Taiyo-no-oka are plotted in the figure, this point will be on a line just extended from the straight line described above. Thus, by introducing the locality of Kagawa Pref. to the figure, it becomes more meaningful. That is, by considering a rain gauge at certain place in Kagawa Pref., the conditions of rainfall that may cause small mudflow damage are that the first-period rainfall amount in two weeks is 100 to 19 mm, hourly rainfall depth intensity after changing point on accumulative rainfall curve made from measured values is greater than 20 mm/h, and effective rainfall is greater than 80 mm. Values greater than 28 mm/h and 125 mm are considered to be a rainfall condition which may cause considerably large-scale mudflow disaster.

5. SELECTION OF DANGEROUS TORRENT FOR DEBRIS FLOW

When occur a debris flow, many factor and inducement become fasten. It was unknown that the magnitude of such individual factor and their combined influence on the occurrence. Certainly, I think on the study of debris flow that it is true way to make evidence the character of each factor. But it is really difficult. Although we cannot understand the intertwined system of factors, we can consider the relation in each factor of the torrent. So we do summarize mathematically character of factors, and do the evaluation synthetically. The method is called multiple variant analysis. Among them a method of discriminant function is usually used for the selection of dangerous torrent for debris flow. As follows are examples attempted in Japan.

There is no doubt that the river bed gradient and rainfall have a definite effect upon the occurrence of mudflows. Apart from the above, such factors as the nature of the soil and vegetation are also said to have something with the occurrence of mudflows. But it was impossible to understand the magnitude of such individual factors and their combined influence on the occurrence of mudflows.

It is impossible to predict theoretically the occurrence of debris flow from such factors since the mechanism of occurrence and movement of mudflow has not been clarified as yet.

This being so, Kobashi et al.³⁾ employed a statistical method in an attempt to obtain an equation for making a judgement as to the devastation of mountain rivers from the environmental factors in the drainage areas. As the object of investigation, they chose the Takayama main line of the Japanese National Railways (Kamiaso - Hidakanayama) running along the Hida River which suffered damage by Typhoon No. 7 on August 17, 1968. The judgement equation was linear and the judgement scoring was used so that the degree of danger could be expressed in the form of

$$y = x_1 + x_2 + \dots + x_m$$

At first, 18 factors were selected for making judgement. However, as a result of x^2 (Greek letter Kai square) test and the elimination test by correlation, the number of factors was reduced to 11, considering other factors to have no statistical relation to the devastation of mountain streams. The 11 factors were the condition

3) S. KOBASHI et al; Koku Shashin Handoku ni yoru Shamen no Anzen do Kaiseki, Shin Sabo Vol. 25 No. 1, 1972.

Table 2

Boundary value scoring 0.0
(Maintain stream)

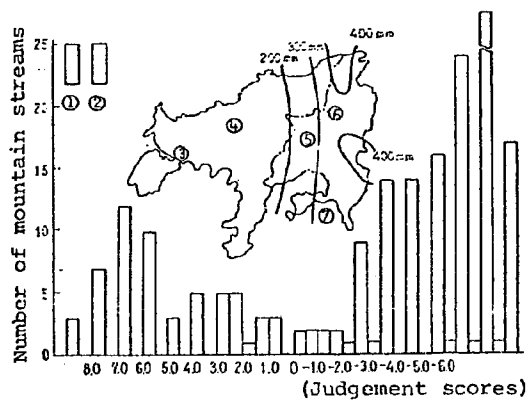
Judgement scoring		Mountain stream	Devastated mountain stream	Incidence
Danger scoring	over 1.0	36	33	92%
	0.0 ~ 1.0	33	18	55
Safety scoring	-1.0 ~ 0.0	58	12	21
	-2.0 ~ 1.0	39	2	5
	below -2.0	5	0	0
Total		171	65	38%

of stream outlet, vegetation, river system frequency, condition of river basin, valley shape (cross section), valley shape (longitudinal section), linear structure, undulations, area of river basin, and the presence and absence of surface water. The analytical results were as shown in Table 1. The paper, which was referred to, did not show the rate of accuracy of judgement to be obtained by comparing the results of judgement with the actual state of devastation. The author of the present paper made calculations from Table 2 and found that this method had an accuracy of about 81%.

The Erosion Control Division of the Public Works Research Institute also made a judgement about the rivers susceptible to the danger of mudflows, employing a similar method as described above.⁴⁾

The object of this study was the mudflow disaster which occurred on the island of Shodo in the Inland Sea in July 1974. The results of the analytical study showed that a factor which had the greatest effect on the judgement was the deposits existing near the river course and the next important factor was the vegetation in the vicinity of the river course. Contrary to the researches' expectations, such factors as the presence or absence of a landslide on the mountainside and the nature of the soil had little effect on the judgement scoring. The frequency distribution of the judgement scores was as shown in Fig. 7 and the accuracy of judgement was about 92%.

4) Erosion Control Division of P.W.R.I and Kagawa Prefectural Government; Shodoshima Dosekiryu Chosa Hokokusho, 1975.



- ① Streams where mudflows occurred
- ② Streams where mudflows did not occur
- ③ Tohosho
- ④ Shodo Island
- ⑤ Kusakabe
- ⑥ Utsumi
- ⑦ Sakade

Fig. 7 Map of Shodo Island, Rainfall Chart (rainfall in 2 days) and the Distribution of Judgement Scores

The accuracy of judgement means as follows:

judgement \ real	dangerous group	safety group	total
occurrence	① 50 torrents	8 torrents	58 torrents
do not occurrence	8	② 137	145
total	58	145	③ 203

$$\frac{\text{① Occured number in dangerous group} + \text{② do not occurred number in safety group}}{\text{③ all total number}} = \text{accuracy of judgement}$$

6. CHARACTERS OF DEBRIS FLOW

This is the most important theme for make a reasonable design the debris flow countermeasure structure. Okuda who attending at this symposium is the first man to achieved quantitative observation and recorded the moving debris flow with the purpose to make evidence characters of debris flow. As above mentioned observation of moving debris flow is in practice at several place. Among them Mt. Yakedake and Sakurajima are achieved and produced several data. Characters of debris flow are distinct as follow; (1) velocity (2) shape of flowing and stillstand debris flow (3) impact force. In addition those to do make analythis, measurement for topographical factors of torrent and other inducements are need. Particularly, I think values on impact force measured in Japanese torrent are larger than the value of Indonesian torrent.

Outlines of characters of debris flow showed as follows.

Some of the studies ever made on the impacts of mudflows will be introduced below.

Takahashi⁵⁾, with the cooperation from the Forestry Agency, conducted a test in which an artificial mudflow was caused in a mountain stream in an attempt to make measurements of the impacts of the mudflow on a closing levee. In this test the gate of an upstream dam was to be opened suddenly to produce a flood with a bore but not so much earth and sand were mixed into the water as to cause a phenomenon deserving to be called a mudflow. But this test resulted in the obtainment of valuable data about the impacts of flood bores. This test showed that the impact pressure of the bore was about twice greater than the hydrodynamic pressure of a steady jet stream of water and about three times greater than the hydrostatic pressure.

Hirao and et al⁶⁾ conducted experiments in an attempt to determine the impact pressure of flood bore, using pure water and Bentonite solution. The experimental results showed that the impact of the bore was 1 to 1.5 times greater than the hydrodynamic pressure of a steady jet stream of water and that the bore impact pressure was greater in the case of the Bentonite solution than in the case of pure water.

$$F = \frac{1}{2} C_{Di} \rho V_o^2$$

where C_{Di} is impact resistance coefficient and

$$C_{Di} = 4 \times 1 - x^2 / (1 + \frac{P}{2P_s} x^3)^3$$

where P and P_s the densities of mudflow and boulder and x is the immersion ratio and $0 < x < 1$. Assume the boulder density to be $P_s = 2.5$ and the apparent density of mudflow to be 2, the maximum impact coefficient (C_{Di}) would be 1.64.

Such test results seem to be well in agreement with the previously discussed test results.

In view of the above research results, it can be said that the impact can be roughly estimated if the velocity and density of the mudflow are know.

5) H. TAKAHASHI, Dosekiryu ni taio suru Sabo Dam no Sekkei Kaju ni kansuru Jikken teki kenkyu (I.R.), Shin Sabo, Vol. 24, No. 2, 1971.

6) K. HIRAO et al; Danpa no Shogekiatsu ni kansuru Jikken teki Kenkyu (I.R.) Shin Sabo, Vol. 24, No. 2, 1973.

It was reported that the velocity of the mudflow involving large boulders which occurred on Mt. Yake⁸⁾ was around 5 m and the mud flow-like earth and rock avalanche which occurred on the island of Sakurajima⁹⁾ had a velocity of about 10 m.

The earth and rock avalanche on Mt. Yake had a density of 1.25 to 2 and that of the island of Sakurajima had a density of 1.8 to 1.9. Assuming that the boulder's specific gravity was 2 and the voids (void ratio: 33%) were filled with pure water, the specific gravity of the earth and rock avalanche was calculated to be 1.7. This is probably the average density of mudflow.

The impact pressures of mudflows can be estimated in this way. However, a mudflow that actually occurs is not a homogeneous fluid but it often contains very large boulders to cause such tremendous impact pressures that a force as heavy as 6 tons acted on a 15cm x 15 cm board according to the estimation made from the pressure of mudflows.

In addition, I hope you to read the advance print of this symposium from page 122 to page 125.

7. A VIEW ON RESEARCH FOR DEBRIS FLOW

Occurrence mechanism of debris flow is not established theory yet. Because plentiful field observation is not found yet. But Daido and others explain on occurrence mechanism.

Separate the occurrence mechanism, I can find 3 types on occurrence phenomena.

- (1) When a collapse cause on the torrent head and its debris run into the torrent channel, provoked deposit begins to move and grow to debris flow.
- (2) The deposit on torrent transferred and change into debris flow without a provoke of collapse.
- (3) Debris of collapse buried a torrent channel likes a dam (so called natural dam). When the natural dam was broken the debris flow occurs.

To make a laboratory test and to make a model of debris flow, there are shortage of datum on field data, I think.

On circumstance for debris flow occurrence, questions are as follows:

- (1) Spring waters have not been qualitatively evaluated.
- (2) The thickness of the deposit in the torrent bed or rather ununiformity in thickness has assumedly some kind of relation with changeability to debris flow but its qualitative valuation is very difficult.
- (3) In many case, the bed rock seems to have been gradually exposed in water fall shape when seen in the debris flow corrosion area after its completion.

7) H. SUWA et al; Dosekiryu Sentan ni okeru Kyoreki no Undo oyobi Sentan Keijo ni tsuite, Annual Report of Disaster Prevention Research Institute of Kyoto Univ. No. 16B, 1973.

8) S. OKUDA; Showa 49 Nendo Dosekiryu Chosa, Matsumoto Work Office of M.C. 1975.

9) M. TABATA; Sakurajima no Dosekiryu to sono Chosa, Shin Sabo, Vol. 28, No. 4, 1976.

- (4) The shape of the bed rock and ununiformity in thickness of the deposit in the torrent bed are mutually related and which of them is more influential to the occurrence of the debris flow, is unknown at present time. But this is very interesting problem to solved in the future investigation.
- (5) Relation between changeability to debris flow and the properties of the soil of sediment (or deposit) on the torrent bed is almost unknown at present time.
- (6) It is true that the torrent which causes debris flow will have a shape capable to converge the rain water, but quantitative studies on the relation between debris flow occurrence and convergent ability have not been sufficiently conducted.
- (7) Geology of torrents in which debris flows occurred is granite zone, volcanic products zone, fault-shattered zone, Tertiary zone, Paleozoic zone and hot spring alternated zone, as reported as surface formations. However, this type of approach to the geology of debris flow has a value similar to say that debris flow occurs any where in Japan as long as torrent exist. It may be meaningful to list such bedrocks related to debris flow but it is required to, on the surface geology of Quaternary, check and study distribution, grading and hardness of talus cone and volcanic fragments, their contact conditions with baserock, degree of weathering and thickness of bed rock, condition of shattered portion in contact with penetrated rock, and small faults.

About the selection of dangerous torrents by mathematical stocustic method, our empirical questions are as follows:

- (1) The range for accuracy of judgement is from about 90% to 70%, and in case of many number of data showed rather smaller percentage.
- (2) Although the torrent seems to be safe because it gets high scoring, the debris flow occurred the truth in that torrent. So at present time, it is difficult to judge an individual torrent to be safe or danger by this method. I think that above mentioned matters gives us negative information to put practical use, but I believe that that method can stand improvement in future.

About characters of debris flow, many question are remained as unknown but only the density of debris flow is relatively understood to us. Necessary to do research debris flow is to get plentiful data at the field, we stand in that stage.

Thank you very much for your kind attention.

2—5. Result on Investigation in Mt. Merapi

Ir. Bambang SUMANTRI

**(Project Manager,
Mt. Merapi project in Yogyakarta)**

RESULT OF OBSEKUATION AT MT. MERADI

BY IR. DJOKO LEGOWO
IR. BAMBANG SUMANTRI

1. GENERAL INFORMATION

It is difficult to understand the characteristics of lahar flow by our present engineering standards. Lahar flow is a mudflow from volcano and it consists of volcanic materials such as ash, sand and boulders, mixed with water.

There are many methods for studying the characteristics of lahar flow, however the main purpose is to know the nature of lahar in order to establish the best countermeasure against it.

Forecasting of lahar flow by an exact method is very difficult, also.

According to the observation in the past, dangerous lahar in Merapi occured when the rain has the intensity of 70 mm within 35 minutes above the elevation of 1200 m. Based on this experience, if such condition occurs, the volcanological observatories, which are equipped with automatic raingauges, will pass the warning "Beware of lahar" to the nearest telephone office. The telephone office at once passes this information to officials concerned.

In order to be able to evacuate the people along certain river in time during lahar flood, Mt. Merapi Project Office has erected lahar observation post along Krasak river, equipped with "gongs" to warn the community.

2. INVESTIGATION ON LAHAR DEPOSIT

The composition of lahar deposit analysed by Schmidt and Adriaanse after Mt. Merapi eruption in the year 1931 showed the portion of 35 % stone, 50 % sand and 15 % ash.

The investigation of lahar composition is very important because it is not easy to investigate quantitatively and directly the lahar flow including the water content. The stone component in lahar has a close relation to the lahar energy.

The ash component has a special appearance related to the mechanism of lahar. The thickness of ash deposit depend on the type of volcano, the distant of the place from the eruption point and the direction of wind during eruption time.

Some studies ever made on lahar deposit will be introduced below.

2.1. Field investigation on lahar deposit has been done in 1973 at the checkdam site of Trising river, Blongkeng river, Putih river and Krasak river.

The purpose of the investigation was to know the composition and the shape of lahar deposit at the checkdam site in order to prepare the checkdam design.

The method of the investigation was geo electrical method using Earth Resistance Tester (electrical resistivity sounding).

The result of the interpretation could be classified into 5 groups based on the difference of resistivity as follows:

- a) group with resistivity (ρ) bigger than 400 Ohm-m. This layer was assumed to be boulders spreading in the loose sand which was smaller in quantity.
- b) group with resistivity = 300 – 400 Ohm-m. This layer consisted of loose sand-gravel with some boulders in side it.
- c) group with resistivity = 200 – 300 Ohm-m. This layer consisted of sand-gravel with boulder lenses.
- d) group with resistivity = 100 – 200 Ohm-m, assumed to be compact sand or volcanic breccia.
- e) group with resistivity = 100 Ohm-m or smaller than 100 Ohm-m, consisted of breccia or old lahar deposit which was compact and permeable.

By considering the local geological condition, the deposit at least could be divided into 3 layers as follows:

- 1) The newest lahar deposit which had a high resistivity. This high value of resistivity showed that it was loose and also very permeable. This layer located on the top.
- 2) The stone layer which had a lower resistivity compared to no. 1, could be classified as an old lahar deposit which was more massive and less permeable.
- 3) The basic layer which had the lowest resistivity could be classified as volcanic breccia or massive lahar.

The depth of the deposits in Trising R., Blongkeng R., Putih R., Krasak R., could be analised as follows:

- 1. Trising R. : the new lahar deposit had a depth between 2,20 and 3,80 m. The basic layer could not be measured due to the unsuitable job site.
- 2. Blongkeng R. : the new lahar deposit had a depth between 1,50 and 3,00 m. The basic layer had a depth between 9 and 15 m.
- 3. Putih R. : the new lahar deposit had a depth of 11 – 12 m.
- 4. Krasak R. : the new lahar deposit had a depth of 4 – 6,50 m. The old lahar deposit had a depth of 12 – 17 m.

2.2 A geological investigation on Krasak R. and the vicinity has been done in 1975.

The investigation area was as follows:

From the national bridge at Tempel up to the upstream area near the village of Jrahah at the elevation of + 600 m. The total length was 7 km, and the width was 0,5 km to the right and the left side from the axis of Krasak R.

The investigation consisted of surface geological mapping, survey of landslide areas along the river, local geological condition, and another general geological condition, related to the countermeasure against lahar flow from Merapi.

The results of the investigation were as follows:

1. Geomorfology.

The catchment area of Krasak R. could be divided into 2 areas as follows:

- a) The catchment area of Bebeng Baru R. and Wader R.; lahar flow in this area mainly consisted of sand and andesitic boulders. The water content was relatively low and the velocity was low, but because of the

big carrying capacity, the lahar flow could transport anything to the downstream.

b) The catchment area of Krasak R. from the confluence point of Wader R. up to the upstream area; this area consisted of compacted old lahar deposit therefore the river flow consisted mainly of water due to small erosion on river bed,--

The result of the survey showed that "landslide" and "rock fall" occurred along the river, due to the unmassive layers, high permeability and slope erosion. The slope of the area to the south was 3 – 5 degree. The rivers flow parallel to the slope, therefore the rivers were "consequent streams".

2. Stratigraphy.

The spreading of the layers found in the investigation area was not homogeneous, vertically and horizontally. This result gave us an important information for designing structures.

The layers could be classified into 4 groups as follows:

- a) Lahar group I
- b) Lahar group II
- c) Lahar group III
- d) River deposit.

a) Group I: the oldest lahar deposit, consisted of lahar breccia from pebbles until boulders with the diameter more than 1 m.

This group was compact, but it was ununiform spreaded. Generally the river bank involved in this area was very steep and high but stable. The average height was 10 m, could be found in the upstream area of Krasak R. The depth of this layer could not be assumed, but it must be very deep.

b) Group II; deposited after group I, consisted of angular pebbles and rounded boulders. This group was not so compact, therefore the river banks consisted of this layer were easy to be eroded. The depth of this layer assumed to be 20 m. It is difficult to find the contact between group II and group I as there were no test pits or boring has been done. The spreading area of this group was smaller compared to the group I, because this group was formed by overflowing process of Krasak R. And on the other hand, the group I was formed before the existence of Krasak R. itself.

c) Group III: estimated as lahar deposit that was formed since the last 20 years, consisted of non homogeneous material from pebbles to boulders which were not weathered yet. The river banks consisted of this layer were easy to be eroded e.g. Bebeng Baru R. The depth of this layer estimated to be 5 – 10 m, and not homogeneously spreaded, due to the direction and frequency of lahar flow. On the big lahar flow, the deposit that was formed could reach the depth of 5 m according to the information from the local villagers. This group took place in Bebeng Baru R. and Wader R. and after mixing with water from K. Krasak flow downwards causing some damages in the downstream area of Krasak River.

d). River deposit: consisted of rounded boulders mixed with sand and gravel.

It was formed by deposition of group I layer and bank erosion in the upstream area. This deposit was not compact; the depth of the deposit was estimated to be 2 m or less, and could be found along Krasak R. upstream up to the confluence point of Wader River.

The result of the investigation showed that there were no faults in the Krasak River area, due to the age of the deposit which were still young from the view point of geology.

3. OBSERVATION ON THE VELOCITY AND ENERGY OF LAHAR FLOW.

It can be said that the energy of lahar can be calculated if the mass and velocity of the lahar are known, because the kinetic energy E can be expressed as follows: $E = 1/2 MV^2$. Without any observation and investigation we often make a mistake on estimating the velocity of lahar. We usually estimate the velocity of lahar too big than the fact, which is not bigger than the velocity of ordinary flood. It is easy to understand that the velocity of eruption lahar is bigger than rain lahar.

It was reported that the velocity of the eruption lahar which occurred on Mt. Kelut in 1919 and 1966 were around 7 – 12 m/sec. Adriaanse (Dutch engineer) measured the velocity of rain lahar in Batang River in 1931. He found that the velocity of lahar was around 5 – 6 m/sec. Riis (Dutch engineer) found the velocity of 6 – 7 m/sec. at the same year in Kuning River, at the elevation of 1000 m.

It is possible to conduct more accurate investigation by the presently modern technology. Based on "the joint study of Sabo Works in the volcanic region" between Indonesia and Japan, Mt. Merapi project office has set up lahar flow observation facilities on south-western foot of Mt. Merapi in Jurang Jero River with the assistance of the Japanese researcher.

Those equipment was provided by Government of Japan in 1977, and are designed to automatically go into operation to make necessary records in the event of a lahar flow, same as the equipment that has been set up on Mt. Yakedake in Japan.

Wire and contact sensors are used for detecting a lahar flow. The wire sensor system detects the occurrence of the lahar flow when wire is broken by the rushing downflow of the lahar. The contact sensor system has electric conductors hanging down over the water of the river so that electric current will flow when they contact the rising lahar flowing down the river. It is possible to know the velocity of the lahar flow by means of the time intervals at which the sensors detect the lahar flow.

There is also a video sensor system, in which a warning signal will be sent out when any change occurs in a specific field of vision on the picture screen of a video camera.

The moment those sensors detect a lahar flow, the cine camera and video units automatically go into operation.

Apart from the above, there are also installed pressure mark-type impact meters on the checkdam of Jurang Jero R. for measuring the impact pressure of the lahar flow.

The results of the observation will be reported below.

3.1. It is regret to say that since the wire sensor system has been set up in Jurang Jero R. no lahar flow has been successfully recorded by the wire sensors and the cine camera.

From on-the-spot observation it is found that the wire hanging over the river was cut by people. From the above finding, Mt. Merapi project come up with the following proposals as to prevent the wire from cutting by the people living nearby, as follows:

1. The wire is buried on the river bed with the depth of 30 cm.
2. The wire is connected to concrete piles which are set in the river course. The size of the concrete pile is 20 x 20 cm, the length is 2,40 m, 1,40 m above the river bed and 1,00 m below the river bed. (see the figure).

The concrete pile has a hinge that expected to be cut by lahar flow, including the wire inside it. The distances between the cross sections where the piles have been set were as follows:

Cross section I — II = 20,70 m.

II — III = 43,30 m.

III — IV = 33,80 m.

The results of observation from November 28, 1977 until December 26, 1977 were as follows:

1. From November 28, 1977 to December 10, 1977 the wire sensor system was in a good condition.
2. On December 17 small lahar flow occurred, cutting the wire IV and the wire was connected again. Erosion occurred on the river bed with the depth of 50 cm.
3. On December 24 lahar flow occurred at 14.00 p.m. On the concrete piles set in 12 places, 10 were flowed and lost but 2 were still stood up on Dec. 26, 1977.

It was found that the wire has been cut again by people before the lahar flow occurred. It was cleared from the unlogical results of the velocity calculation that had been obtained as follows:

$$t_1 = 0 \quad v_1 = 0$$

$$t_2 = 0.60 \quad v_2 = 0,60/43,30 = 0,0138 \text{ m/sec.}$$

$$t_3 = 371,90 \quad v_3 = 371,90/33,80 = 11,002 \text{ m/sec.}$$

It is difficult to obtain a good result unless the disturbance mentioned above can be solved, for example by moving the equipment to another safety place. It is impossible to guard the equipment during night and day in the present place, because that place is located just on the forbidden zone of Mt. Merapi.

3.2. Impact pressure.

In order to measure the impact force of the surge of lahar flow, impact pressure meters were installed on the upstream surface of wings of Jurang jero checkdam in 1977.

Of the impact pressure meters set in ten places, only four were operated well during the occurrence of lahar flow on December 24, 1977. The measurement of diameter of impact marks on the aluminium plates showed the results as follows:

Impact mark	Impact pressure meter no.	Diameter of impact mark
	E	3,85 mm.
	J	4,00 mm.
	F	2,85 mm.
	C	2,30 mm.

The relationship between diameter of indentation and force acted had been experimentally obtained in Japan. This relationship can be drawn in a calibrating curve. Values of impact forces obtained from the calibrating curve are as follows:

No.	E	J	F	C
Indentation diameter (mm)	3,85	4,00	2,85	2,30
Impact force (ton weight)	0,325	0,35	0,125	too small
0,267				
(average)				

According to these values, an average force 0,267 ton weight acted at center of flow to the 15 x 15 cm aluminium panel. Small values obtained by this measurement means that probably there were impacts of muddy water only. It is logical that a considerable difference in breaking actions is expected between the impact of muddy water and the impact of large rock even if velocity of each portion of lahar flow is similar at a certain time.

The lahar flow occurred on December 24, 1977 seems to be smaller in scale than that occurred on November 25, 1976. 29 persons were died, 17 houses were damaged, 1 primary school building was damaged, 2 cars were damaged, 12 ha of rice fields were flooded and river bed was eroded (about 7 m in depth) in the downstream side of Jurang Jero checkdam by the lahar flow on November 25, 1976. The lahar flow occurred on December 24, 1977 had destroyed the protection wall of the bridge abutment (about 30 m in length) on Krasak river in the village of Salam.

During the occurrence of lahar flow on November 25, 1976 photographs had been successfully taken by Mr. T. Mizuhara (Colombo Plan Sabo Expert assigned to Mt. Merapi Project) showed the lahar flow rushing through the overflow section of Jurang Jero checkdam.

4. CONCLUSION AND SUGGESTIONS

CONCLUSION

1. The purpose of the investigation on lahar deposit that had been conducted in Mt. Merapi in 1973 and in 1975 are mainly to know the composition and the shape of lahar deposit at that time in order to prepare the checkdam design at certain places.
2. Since the study for making a master plan for land erosion and volcanic debris control in the area of Mt. Merapi has been carried out from 1977, the study of lahar deposits has been intensively conducted.

This study consists of:

- a. Digging the test pits of approximately 4 - 6 m in depth with a bottom area of 1.5 m x 1.5 m at several places on Krasak river.
- b. Soil tests of material on Krasak river by grain size, specific gravity and density at the pits.

On the other hand, measurement of sediment load had been conducted too.

This measurement consists of:

- a. Measurement of suspended load at several places on Krasak river, Progo river and Opak river by observing stream discharge.
- b. Measurement of bed load by digging pits of approximately 10 m x 10 m x 2 m (L x W x D) at several places on Krasak river and measure sediment deposition in pits after flood.
- c. Sieve test of materials composing the river bed at where bed load measured on Krasak river.

The studies mentioned above will be continued in 1978/1979, and in Japan data and information compiling were carried out.

3. Equation for motion of the lahar flow is not clear yet at this time because viscosity, specific gravity and mixing rate of sediment, rock and gravel in the lahar flow are just now compiled and analysed by the Merapi Master Plan Study Team.

An increasing knowledge has been gained about the lahar flow on Mt. Merapi. However, there are still many questions to be solved and things to be done, such as the clarification of the mechanism by which lahar flow occur, the relation between rainfall and occurrence of lahar flow, and more advanced investigation on their realities. Now we are aware that we have just reached the initial stage of the difficult task.

SUGGESTIONS.

1. In view of the above observation results in Mt. Merapi, it can be said that human factor is an important problem in the area. It is difficult to obtain good results unless the human disturbance can be prevented. This can be done by moving the wire sensor system to another safety place where we can guard the equipment easily. However, this place should not be located in the forbidden zone and should be densely populated.

There are two alternatives:

- a. To move the wire sensor system downward to the village of Ngepos near the evacuation bridge on Putih river.
 - b. To move the wire sensor system to Krasak river (which is the most dangerous river in Merapi area) near the lahar pocket at the village of Kranggan.
2. In order to obtain good results in investigation of impact force, it is suggested to install impact pressure meters in Krasak R. too (which is considered to be the most dangerous river), for example on the checkdam in the village of Kranggan.
3. Relation between rainfall and occurrence of lahar flow is not clearly defined yet because at present we only make assumption based on the experience in the past, and quantitative studies on this relation have not been sufficiently conducted.

Therefore this is a very interesting problem to be solved in the future investigation.

It is hoped that research on the forecast and prediction of lahar flow will be more progressed in the years to come.

4. Based on the "Scope of Works on Japan—Indonesia Joint Study Plan on the Sabo Works in the Volcanic Regions", the joint study plan will be finished at the end of 1978/1979 fiscal year.

However, there are still many problems to be solved as already mentioned above. Therefore it is suggested to extend the joint study at least one more year.

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Fig. 1. Location of wire sensor system at Jurang Jero river.

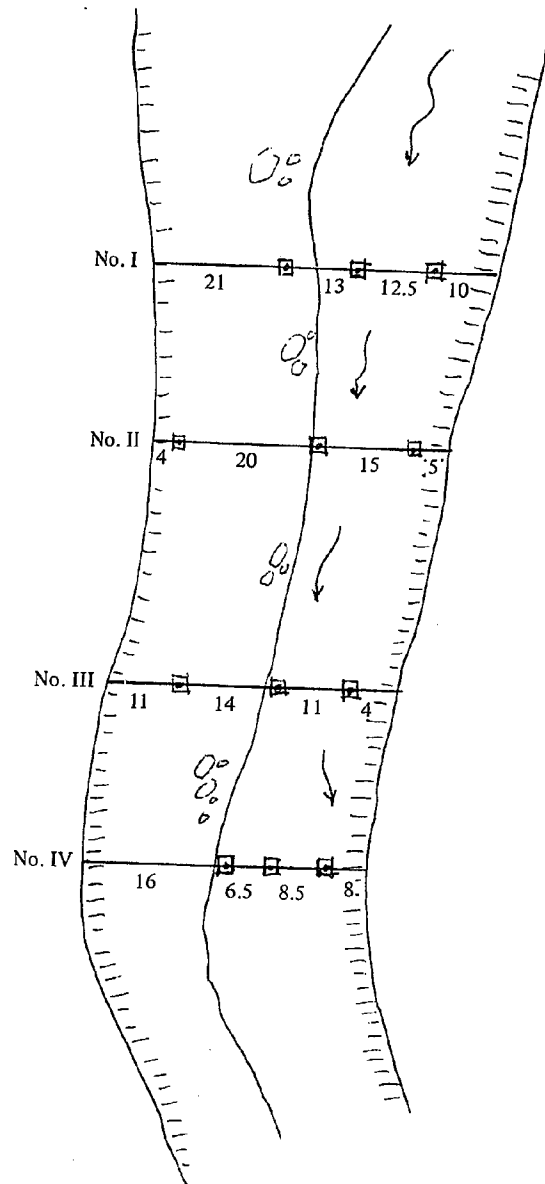


Fig. 2. Detail of concrete pile.

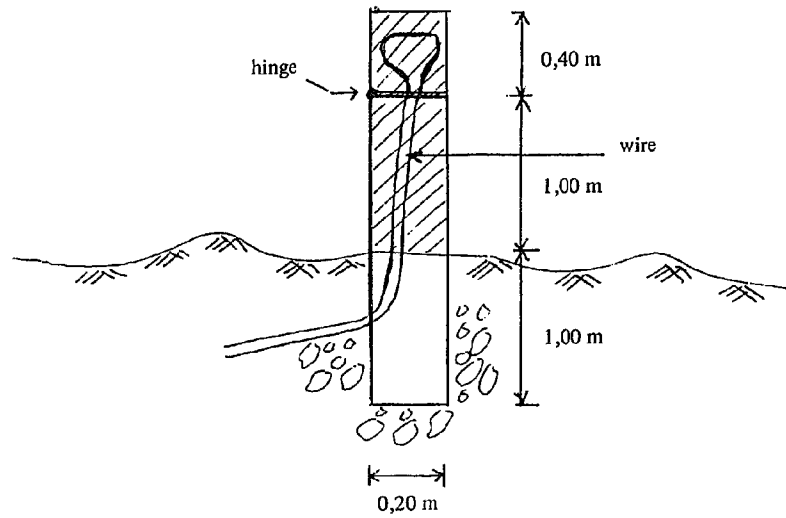


Fig. 3 The scheme of the system

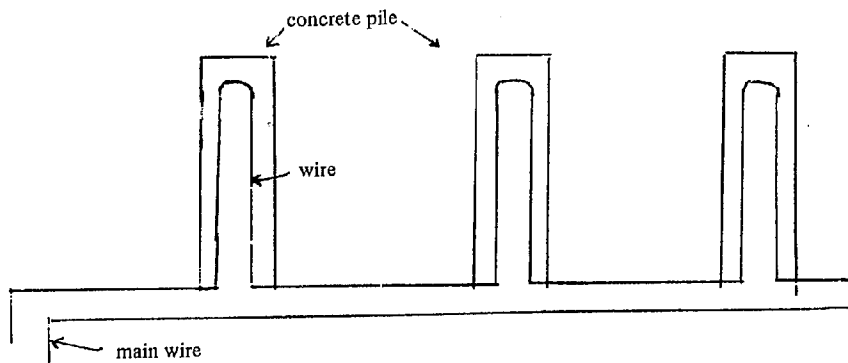
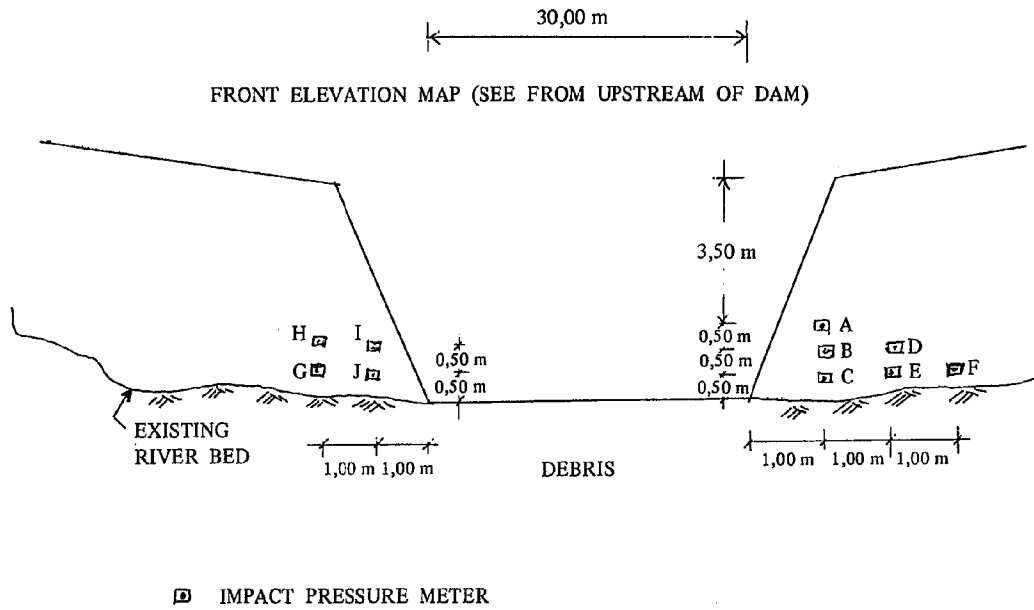


Fig. 4. Location of installation of impact pressure meters at Jurang Jero river.



Ir. Bambang's photographs



Mudflow was flowing down through Jurangjero river



Mudflow was flowing down at Jurangjero check dam



**Location of wire sensor and concrete block
The small house was for debris currentmeter recorder**



Check dam where the impactmeter was set up at wing side

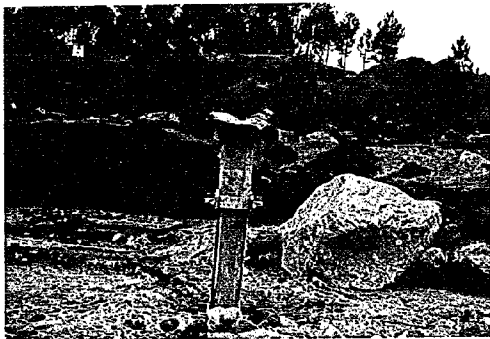


Boulder at downstream of K. Krasak



Railway bridge had collapsed by mudflow at 1975

The installation of wire sensor system at Jurang Jero river.

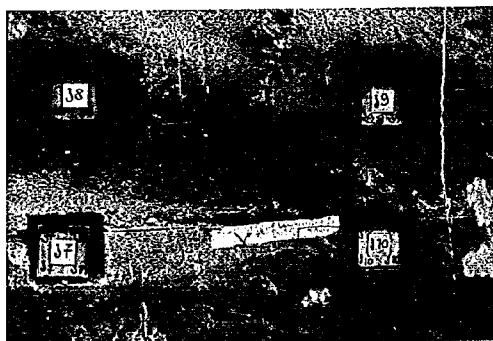


Concrete pile under construction. The wire is buried below the river bed.

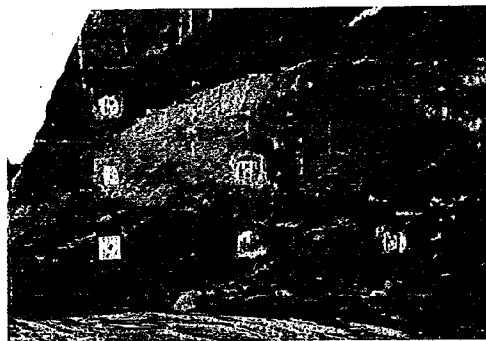


After completion

The installation of impact pressure meters on the Upstream surface of wings of Jurang Jero checkdam.



Under construction



After completion

2-6. Result on Investigation in Mt. Yake and Sakurajima

- i) Results of observation of Mud flows at Mt. Yake
- ii) Mud flows on Sakurajima island and its investigations

Mr. Osamu YAMAUCHI

(Erosion Control Division, P.W.R.D)

i) Results of Observation of Mudflows at Mt. Yake

Compiled by
Osamu Yamauchi

FOREWORD

Observation of mudflows at Mt. Yake was initiated by the Matsumoto Sabo (Debris Prevention) Construction Office of the Ministry of Construction in 1970. Since the next fiscal 1971, the surveys and observations have been carried out under the powerful support and cooperation of the Disaster Prevention Research Institute of the University of Kyoto.

Owing to the data accumulated through a long period of observation and improvement and completion of the method of observation, the real form of mudflow has come to be known gradually.

The results of observations in the respective years are reported in the "Matsumoto Sabo Office Technical Reports No. 5 and 7."

The present report is a representation of the foregoing two reports.

1. MT. YAKE AND ITS ACTIVITIES

1.1 Outline

Mt. Yake (2,458 m) is located nearly at the center of the country of Japan. It is an only active volcano in the North Alps of Japan and a tholoide volcano belonging to the Norikura Volcanic Zone.

Recent eruptions of Mt. Yake started on December 8, 1907 and occurred five (5) times in 1907, two (2) times in 1908 and twenty-three (23) times in 1909. The eruption of June 6 produced a great extending from a point at a height of about 1,900 m on the platform between the Shimohori Valley and the Nakahori Valley on the east side of Mt. Yake almost to the east wall of the summit, and the mudflow occurring this time blocked the Azusa River and created the present Taisho Pond. Thereafter, in the years of Taisho (1912~1926), the volcano erupted twice in 1915, thrice in 1916 and once in 1925. While the eruptions in the years of Showa era (1926 ~) will be described later, a great eruption occurring suddenly in June of 1962 indicated vividly the presence of Mt. Yake as an active volcano.

The Taisho Pond had a natural pondage of 430,100 m³ in (1926), but the sediment amounted to 400,000 m³ until 1952 so that the natural pondage decreased to 7 percent of the initial condition. The pondage increased once to 714,000 m³ when a water intake gate was completed down the Taisho Pond in the 3rd year of Showa (1914) by the hands of Tokyo Electric Power Company. But, due to intensive inflow of sediment thereafter, it decreased to 223,500 m³ in 1958, to 202,000 m³ in 1959, to 178,000 m³ in 1960 and to 153,000 m³ in 1962. Thus, the Taisho Pond may be said to be following a path to the end.

- Dam
- - - Groundsel
- = Emergency debris prevention dam
- ≡ Emergency debris prevention consolidation work
- ... Newly eroded valley
- ▲ Mountainside work

- Ash coverage 1 ~ 2 m
- ☞ Mudflow and sediment deposit
- Crater (new)
- ♠ Mountain hut
- △ Old crater
- Crater lake



- ① Nakao Ridge
- ② Mt. Yake
- ③ Kamikamihori Valley
- ④ Kamihori Valley
- ⑤ Nakahori Valley
- ⑥ Shimohori Valley
- ⑦ Kamikochi
- ⑧ Kappa Bridge
- ⑨ Imperial Hote
- ⑩ Kamikochi Hot Spring

- ⑪ Tashiro Pond
- ⑫ Taisho Pond
- ⑬ Taisho Pond intake gate
- ⑭ Yakedake Office
- ⑮ Kama Tunnel
- ⑯ Nakanoyu
- ⑰ Ridge
- ⑱ Sakamaki
- ⑲ Mt. Roppyaku
- ⑳ Mt. Kasumizawa

1.2 Eruption in 1962

On 19 June 1962 at about 21:50 hours, the mountain started activity with a big sound, and this activity was a complete fissure eruption with an explosive cleft extending in the form of a hood from a point below the Katanokoya hut on the Nakao Ridge along the path up to the summit of Mt. Yake over the Akuzawa collapse on the Gifu Prefecture side. Now taking the phenomenal changes apparently brought about by the activity, both Nakanoyu and Sakamaki hot springs had a change in the temperature as well as the volume of the springs about two or three days before the eruption, and in the region of Mt. Yake, there were earth sounds from about 20:00 hours. Further, there were strong earthquakes experienced in the vicinity of Kamikochi prior to the eruption of June 17. Upon eruption, the smoke rose right up in the form of a mushroom, and it became dark all over the area on account of ashes and it was about 30 minutes later that the moon could be seen. The ashes deposited in a thickness of 3 cm at Kamikochi and fell on the Matsumoto City at about 23:30 hours. In the vicinity of the Nakanokoya hut on the Nakao Ridge, there was a fall of rocks of a size of 50 cm, and the hut was destroyed completely except some pillars, and two caretakers of the hut were injured seriously. On the next 18th day, the ashes continued to fall until about noon in the area of Kamikochi, and the Hodaka Range was obscured and scarcely seen, while it was difficult to walk because of the volcanic ashes entering into the eyes. In the afternoon, the ashes continued to drift as if they were snowdrift in winter because of a strong wind.

On June 19 at about 14:11 hours, eruption occurred again with three big sounds, and at about 15:30 hours, a mudflow ran down with a white smoke from the upper parts of the Kamikamihori Valley to the Taisho Pond, and the occurrence seemed to be instantaneous as the people who observed the mudflow said that its speed was such that it took only several seconds from about the summit to the Taisho Pond. As the result, there was a deposit of 2 ~ 3 m on the river bed down the Kamikamihori Valley. Deposition was also intensive at the upper parts, and by this mudflow, big trees along the river were swept away. The mudflow included boulders and ran down to the lower parts. It was like a paste of gray volcanic ashes and stone with water and was still muddy even one week after the flowdown, and it was difficult to walk thereon. At about 16:30 hours, there was a small explosive sound.

From about June 21, the eruptive smoke was reduced considerably, and there was a relatively calm period until July 11.

On July 12 at about 05:45 hours, eruption occurred again. This eruption was presumed to be at the site of eruption of June 16, near the summit and on the Kamikochi side. Volcanic ashes and boulders fell on the Kamihori Valley. Then, with a small precipitation (27.2 mm) from the midnight, mud flow containing 5 m boulders occurred twice from the Kamihori Valley and buried the prefectural road along the Azusagawa River. The fall ash was present only between the lower part of the Taisho Pond and the Kamagafuchi, and the smoke from about the point of eruption in 1915 intensified the strength, while there were smokes rising out of many other places.

On July 26 past 20:00 hours, eruption was confirmed with volcanic ashes rising with a small sound from the place of eruption of July 12. The ashes due to this eruption were carried on wind toward the Gifu Prefecture.

On August 9, with earth sounds from about 09:10 hours, eruption occurred at about 09:11 hours, and the summit was clouded dark by the ash. Because of a strong wind due to a typhoon, the fall ashes were scarce in the vicinity but flowed toward the Mt. Hodaka. The earth sounds continued for about 5 minutes, and the

place of eruption was presumed to be near the place of June 17.

On September 16 at about 07:05 hours, eruption occurred again. The weather was fine on the day, but there was a shower for about 10 minutes after the eruption. The eruption was of a similar scale to that of June 17 but occurred at the same place so that the smoke rose right up to about 100 m. It involved little ash and ended in smoke so that there was no damage.

After September 16, eruptions occurred at a rate of several times a month, but they were of small scale in the explosive sound, smoke and fall ash. Eruptions with only explosive sounds were observed often. But, on account of frequent flights of jet aircraft, they are scarcely identifiable from the mach sounds, and it is not known whether or not they were actually explosions.

1.3 Effects of 1962 Eruption upon the Region Near the Summit and Four Valleys

1.3.1 Region Near the Summit

By the fissure eruption in the night of June 17, Mt. Yake had a black cleft produced in the form of a hoof down the old crater. The fissure is in a scale of 5 ~ 50 m in width, about 10 m in depth and about 0.7 km in extension. The crater presumed to have raised a great quantity of smoke and that giving smoke presently are dark black so that it is difficult to estimate the depth but that they are considered to be of a considerable depth. The fall ash forms deposits of 2 m near the crater, 0.6 m at the 80 m lower part and 1.1 m near the Motoyake-dake hut.

By runoff of the mud flow, a newly eroded gully was created. It is of a scale of 5 ~ 10 m wide and 2 ~ 7 m deep and joins the Kamikamihori Valley at the upper part. Thus, near the summit, there are smokes rising everywhere and much ash so that it is difficult to walk, while several strips of newly eroded gullies are created so that mudflows running down to the lower parts are apprehended.

1.3.2 Shimohori Valley

Now looking the effects of the eruption on the four valleys in the jurisdictional area (or Shimohori, Nakahori, Kamihori and Kamikamihori Valleys), the Kamihori and Kamikamihori Valleys had mudflows occurring frequently after the eruption. Before the eruption, the mudflows occurred only a continued precipitation of 50 ~ 70 mm normally, but after the eruption, they tended to occur at about 30 mm. Particularly, the Kamikamihori Valley had been a valley where large scale mudflows had not been seen for some time in the past years. In this year, these valleys had no mudflow prior to the eruption except one occurring in the Shimohori Valley on June 13.

Shimohori Valley was little affected by the eruption of Mt. Yake this time, only by the ashes. But, here, it is considered that the mass of mountain and the surfaces of collapse were affected considerably by the earthquakes accompanying the eruption so that the collapse would be accelerated.

The mudflow occurring in June in Shimohori Valley was that flowed out in the night of June 13 before the eruption, and its scale was comparable to that of the mudflow in Kamihori Valley on July 12. Shimohori Valley has no streamflow, and with a continuous rainfall of 50 mm or more, there is a fall of a height of about 40 m formed at the end of the collapse of the uppermost part, and the mudflows are induced normally by this fall.

After the eruption, there was only a small scale of mudflow on July 2. Thereafter, collapsing occurred intensively near the fall in the upstream, and the mud of collapse deposited here was estimated to be 70,000 m³.

Thus, depending on the rainfall hereafter, it will surely flow out so that in the bed compacting work now being carried out in the downstream, utmost care must be exercised and planned execution must be made.

1.3.3 Nakahori Valley

In the Nakahori Valley, there is no direct effect of the eruption nor mudflow observed. However, it was presumed that there were falling ashes by the eruption and falling rocks due to boulders by the eruption of July 12, resulting in a considerable amount of deposits in this valley. But, as this valley has three dams and is bending for about 70 degrees at the middle part (near the No. 3 dams), it is considered that a mudflow may occur as in the other valleys but has its force relieved at the upper part so that it does not run down to the lower part.

1.3.4 Kamihori Valley

This valley had the mudflows occurring most actively among the four valleys after the eruption. At present, below the confluence of the left and right branches is located No. 1 dam, and No. 2 dam is being constructed at about 150 m up the No. 1 dam along the left branch (completed in December 1962).

After the eruption, the mudflows were occurring successively on June 22, July 1, July 2 and July 12. Particularly, the mudflow of July 12 began to flow at about 12:40 hours, checked the Azusa River and reached to the shoulder of the National Park road. Additionally, at about 15:12 hours of the same day, there was a large scale of rush of mudflows from both branches of the valley. The rush buried the road, flowed into the Taisho Pond and buried the intake gate of Tokyo Electric Power Co.

According to the observation near the No. 1 dam, the mudflow first occurred in the right branch, joined the mudflow occurring several tens seconds later in the left branch and flowed down the valley. The mudflow in the right branch included boulders as large as 5 m, and its speed was estimated to be about 13 m/sec. The mudflow in the left branch was really a flow of mud carrying rocks of 0.5 m to 1.0 m on the surface, and the rocks were transported as if they were wooden blocks.

By these several mudflows, both branches of the Kamihori Valley had the bed raised for 2 m average over that of the previous year respectively, and the No. 2 dam in work above the No. 1 dam was completely buried.

Further, the uppermost parts of both branches were eroded considerably, there were points in the form of a fall. Particularly, at a point 150 m up the No. 2 dam in the left branch, collapses from both banks were intensive, and they deposited to form a natural dam with a height difference as large as 10 m. Such a condition is seen from place to place up to the upper part to form stepwise deposits. Such sediment is in a very unstable condition and, depending on the precipitation hereafter, has a possibility of flowing down in a mass of big mudflow.

1.3.5 Kamikamihori Valley

The eruption in the night of June 17 occurred in the upper part of Kamikamihori Valley. As the result, in the upper part are accumulated rocks and volcanic ashes emitted at the time of the explosion. The mudflow of June 19 occurred in this area and flowed into the Kamikamihori Valley, and by the longitudinal erosion of this mudflow, there were produced in the upper parts of Kamikamihori Valley three strips of newly eroded gullies having the source in the crater of eruption. Further, in the upper parts of the valley are stepwise deposited sediments transported by the mudflows.

The mudflow of June 19 was in a state of cement paste and rushed down to the Taisho Pond, and in the lower parts, the river bed was raised for 2 m average.

However, with subsequent small floods, the longitudinal erosion was intensive down the valley from the middle part. Thus, there are places down the middle to lower parts showing a reduction of 2 ~ 3 m below the old river bed.

In short, this valley had the river bed raised by the eruption, and it was assumed that a mudflow of about $200 \times 10^3 \text{ m}^3$ (including that run off to the lower parts) was generated this time, while there were formed in the upper parts of the Kamikamihori Valley new valleys of erosion leading directly from the crater.

The eroded valleys has a profile of about 5 m in width and 2 m in depth at the point of confluence with the Kamikamihori Valley. But, as they approach the crater of explosion, they join the crater in a width of 10 m and a depth of 7 m. In this region, the ashes are deposited in a range of 0.5 m to 2 m and are in a form of paste so that depending on the rainfall hereafter, they may affect burial of the forest area in the middle parts and the Taisho Pond (main stream of the Azusa River) in the lower parts.

1.3.6 Origin of the Taisho Pond

The Taisho Pond was created as the Azusa River was checked by a mudflow of Mt. Yake, and this mudflow had a width of about 330 m and a depth of 2.5 m at the thinnest part. Upon elapse of 3 hours, the river had a considerably extended width because of the back flow of river water, and on the next day, the lake had as large a longitudinal axis as 1,660 m.

In the previous month to that of the big eruption, Mt. Yake had already started its activities and had a small eruption with a mudflow running down along the Shimohori Valley and checking the Azusa River to form a small lake here temporarily. On the day of the eruption, at about 08:00 hours, the river water became muddy suddenly without change in the weather, and withered and damaged trees flowing down the river were observed reportedly near Shimashima in the lower parts of the Azusa River. Now considering the time, this is only about 30 minutes after the big eruption and is thus probably due to breakage of the small lake dammed up on the previous day, yet surprising is the speed of the mud flow. From generation until the late years of Taisho, the Taisho Pond had little change in the height of the water surface, but its area and volume decreased gradually. Thereafter, with a deposit of collapse formed near the drain port, the water level was elevated, and the height of water surface was greatly increased. Thus, the lake proceeded toward rejuvenation to a state nearly equal to that in July of the 4th year of Taisho (1915), then it had the volume increased and grew to a state far larger than that at the time of formation. Consequently, it came to have a maximum depth of 6.06 m, but subsequently it had its form began to shrink. However, the shoreline of the lake had a smaller rate of shrinkage than that of the area. As the result, the tended to increase by about 0.013 average every year. This means remarkable development of a feather-like land along the lakeshore and indicates, along with lowering of the drain port, that the Taisho Pond is close to its extinction (according to the History of Azumi Village).

The sediment buried in the Taisho Pond in the recent years is due largely to that transported from the basin up Kamikochi. That is, the sediment deposited in an amount estimated to be $50,000 \times 10^3$ on the river bed between Yokoo and Taisho Pond ran down gradually to the Taisho Pond. In these years, the influences due to the mudflow and flow of mud paste in Kamikamihori Valley and flow at Senjojawa are remarkable.

By the eruption of Mt. Yake this time, a mud paste and several mudflows ran down from the Kamikamihori Valley, and the upper parts of the Taisho Pond were buried completely by the sediment. As the sediment moved gradually to the lower parts, the depth of water at the center of the pond became shallow. The mudflow occur-

ring from the Kamihori Vally with the eruption checked the main stream of the Azusa River, and this flowed back and buried the intake gate of the Tokyo Electric Power Co. at the lowermost part of the Taisho Pond. Presently, the total discharge of the Azusa River up the Taisho Pond is drained from the discharge port of the Tokyo Electric Power Co. Should the discharge allowable to drain be exceeded in a flood hereafter, there is a possibility of the houses in the upper parts being affected by elevation of the water level due to pool of water.

2. MUDFLOW OBSERVATION EQUIPMENT AT MT. YAKE

The facilities for observation of mudflows are distributed with emphasis placed on the Kamikamihori Valley (Figure 2-1).

Machines and instruments developed specifically for observation of mudflows are scarcely available commercially. The observation machines and instruments are largely those developed or devised and improved by the Disaster Prevention Research Institute of Kyoto University.

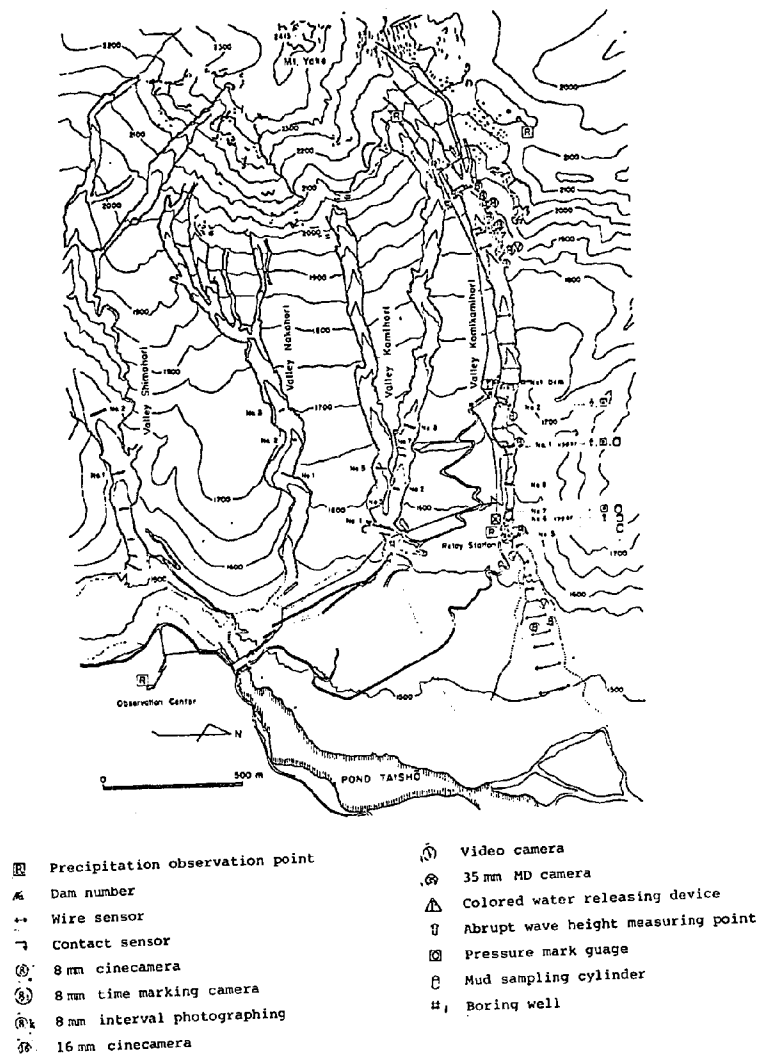


Fig. 2-1 Mt. Yake Mudflow Observation Equipment Array Diagram

1) Speed of the leading edge

With a number of sensors arranged along the path of a mudflow, the time at which the leading edge of the mudflow passes the respective sensors is recorded automatically, and from the distance between adjacent sensors and the time of passage between them, the mean speed in such section is obtained.

For the sensor, there has been used since the last year a wire sensor which transmits an electrical signal when a wire extended horizontally at a height of about 1 m over the gully bed is cut by the leading edge of a mudflow. This type of sensor, however, is shortcoming in that once the wire is cut, it is not usable until the wire is extended again. Thus, as a new type of sensor, there has been set for test a contact sensor which transmits a signal with an earth current flow when the tip end of a suspended conductor comes into contact with a mound of mudflow or a video sensor which transmits a signal when there is a change in the image within a particular field on the receiving surface of a video camera.

2) Water level and discharge

For the water level, a scale was provided on the wing of a check dam, and the water level in the spillway was recorded by interval photographing in use of an 8 mm cinecamera. For measurement of the speed of a muddy stream occurring successively to a mudflow, a solution of a coloring matter (Uranine) was dropped at an interval of about 10 seconds onto the water surface to color the stream, and the movement of the colored portion was followed by an 8 mm cinecamera. The discharge can be calculated from these records of pictures if the cross-sectional area of the spillway and the velocity are known.

3) Forms of flow movement

To take the forms of flow of a mudflow at various places of its path or, more particularly, deformation when the mudflow is flowing down the debris prevention dam and the condition immediately before the stop in the alluvial fan in the lower parts, various kinds of cameras were installed as illustrated in Fig. 2-1. These cameras were so arranged that in use of the sensors described in paragraph 1), photographing would be started automatically as soon as the leading edge of the mudflow entered into the field of the respective cameras.

Now describing briefly the objectives of these cameras:

The 8 mm cinecamera was intended for continuous recording of the dynamic conditions;

The 35 mm constant interval photographing camera for recording of images of high resolution;

The stereo camera for recording and graphic representation of the rising part at the leading edge of the mudflow; and

The video camera for repeated video recording over long hours with monitoring.

4) Amount of rainfall

A one month rain gauge was installed at the Nakao Ridge near the summit of Mt. Yake, a daily rain gauge beside the measurement room, and a weekly rain gauge at the Yakedake Branch Station.

5) Ground water level

As an item of investigation of the water balance related closely to the mechanism of generation of the

mudflow, boring was carried out at two places (to a depth of 55.45 m) in the mountain base at the midpoint of the stream side of Kamikamihori Valley and the Kamihori Valley, and water level meters were set for continuous measurement of the ground water level.

The locations of these boring points are shown in Fig. 2-1, and the columnar diagrams of the boring points are shown in Fig. 2-2.

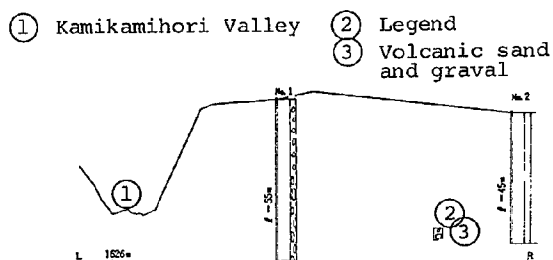


Fig. 2-2 Ground Water Measurement Positions and Geological Condition Map

6) Mud sampling

Mud sampling cylinders were set (at 10 places) in the holes provided in the check dam, and the constituent materials as the leading edge of the mudflow overflowed the dam were collected.

7) Movement of gravels

Large gravels (with a diameter of 0.5 m or more) in a specified section (Fig. 2-3) of a gully stream were color marked with paints (130 gravels in blue color and 69 gravels in green color), and after generation of a mudflow, the locations of discovery upon downstream survey were plotted on a map for observation of the movement of gravels by one mudflow.

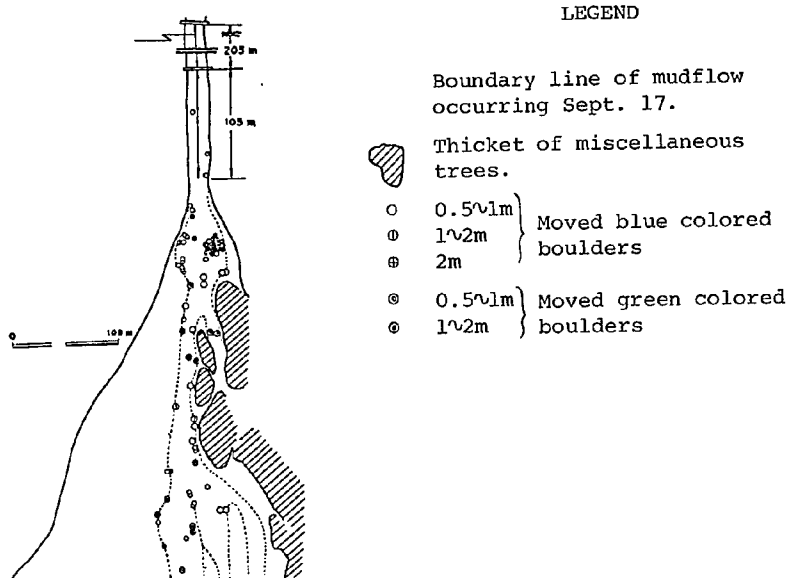


Fig. 2-3 Installation Positions and Flow Down of Boulders in Boulder Movement Observation (17 September 1972).

8) Impact force

To estimate the intensity of the impact force of a mudflow hitting the check dam or standing large gravel, Pressure Mark Gauge were set (at 10 places). This gauge has a conical projection of steel kept in contact with an aluminum plate, and from the size of the mark of the projection thrust into the aluminum plate, the pressing force (impact force) is estimated, and the pressure receiving plate has a size of 15 cm x 15 cm. The structure is illustrated in Fig. 2-4.

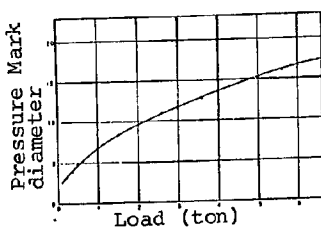


Fig. 2-4 (a)
Schematic Diagram of Pressure Mark

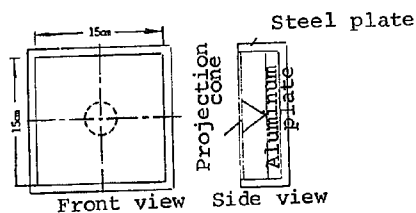


Fig. 2-4 (b)
Curve of Correlation of the Load of Pressure Force and the Mark Diameter

3. OCCURRENCE OF MUDFLOW AND RAINFALL

With respect to the mudflows generating on Mt. Yake, it is known that the peak hour of 10 minutes mean precipitation and the time of generation of mudflow shown good correspondence. In the following will be shown some of the relations between the 10 minute precipitation and the mudflow generation.

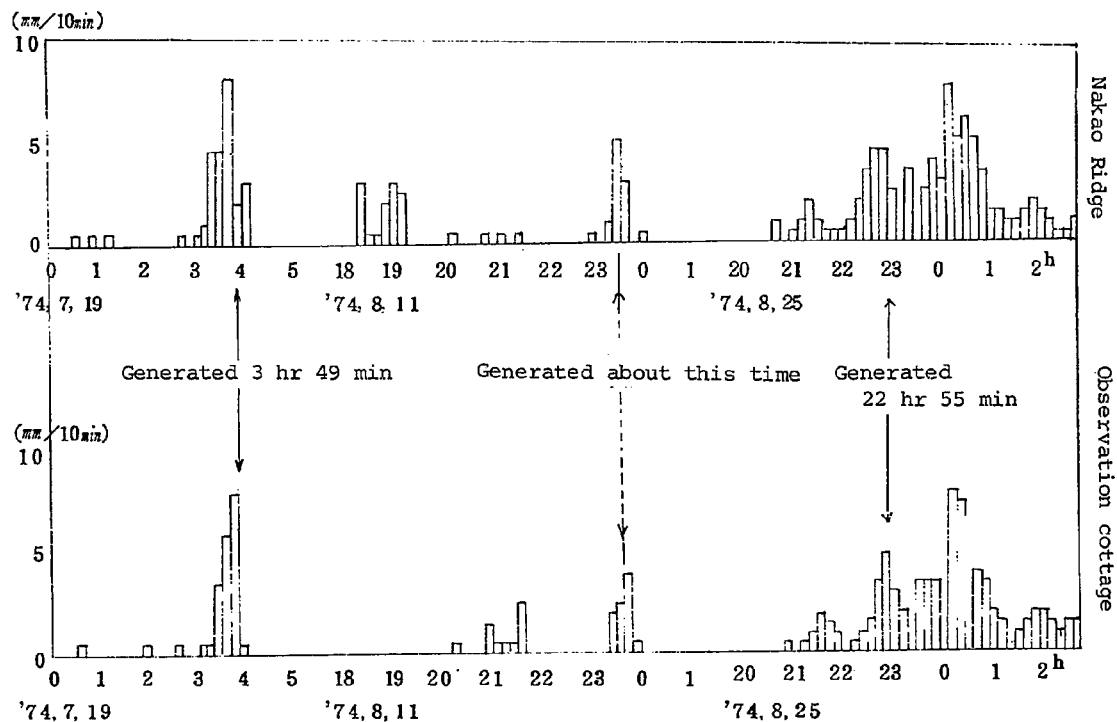


Fig. 3-1 Mudflow Occurrence and Every 10 Minute Precipitation

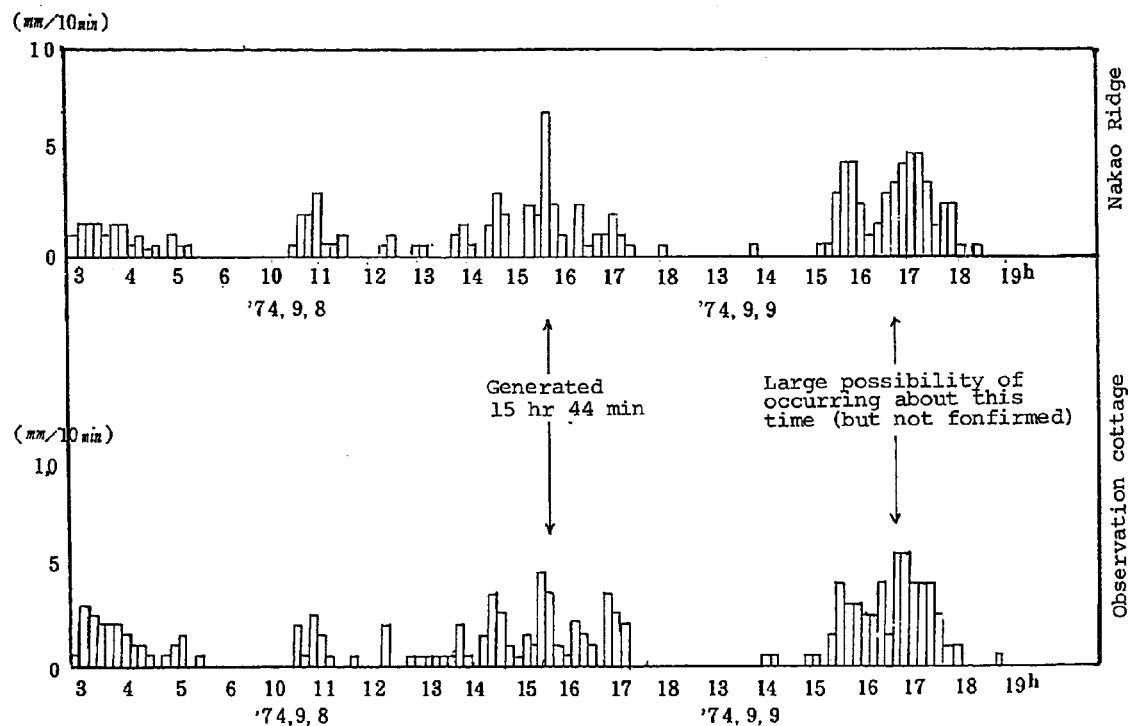


Fig. 3-2 Mudflow Occurrence and Every 10 Minute Precipitation

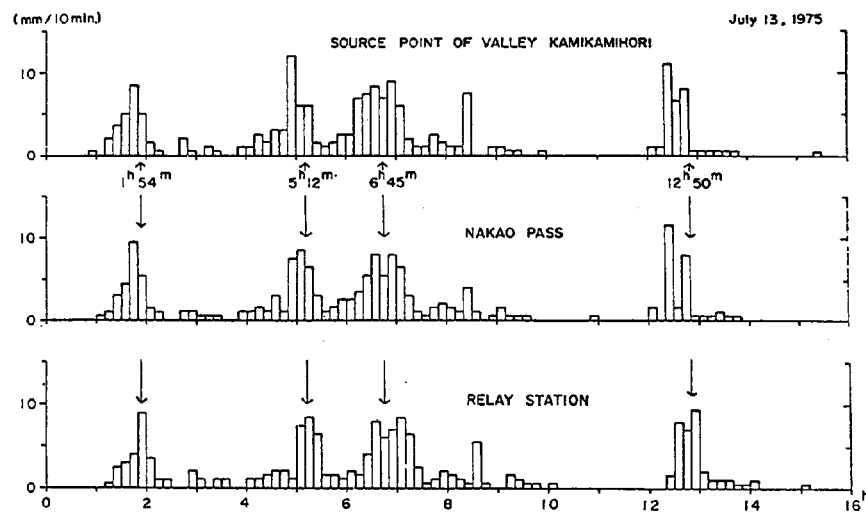


Fig. 3-3 Every 10 Minute Precipitation and Mudflow Occurrence (↓)

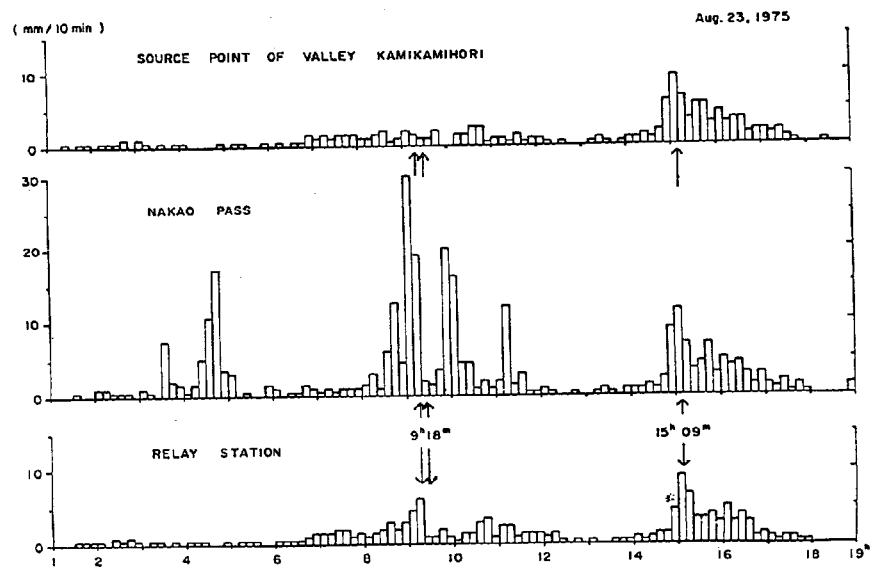


Fig. 3-4 Every 10 Minute Precipitation and Mudflow Occurrence (↓)

It has so far been maintained that a mudflow occurs when the following two conditions are met: one that due to heavy precipitation, the deposits in the valley bed have a sufficiently elevated water content (this condition may be brought about by a relatively small rainfall intensity if it lasts for long hours, and what matters here is not the rainfall intensity but the total precipitation); and the other that there is an intensive rainfall (of large rainfall intensity). Whether or not this is applicable to the mudflows on Mt. Yake will be tested in the following.

Figures 3-5 through 3-7 show the rainfall conditions hourly rainfall and continuous rainfall in 1970 to 1974 (Fig. 3-7 representing the data of 1972 to 1974) versus occurrence or non-occurrence of mudflow. According to the data at the field observation cottage, in the objective area of observation at the east base of Mt. Yake, the mudflow occurs at a probability of 60% if the maximum hourly precipitation is higher than 11 mm and the continuous precipitation reaches 20 mm or more. The hourly precipitation referred to here represents, when a mudflow has occurred, the hourly precipitation at that time or, when there is no occurrence of mudflow, the maximum hourly precipitation. The continuous precipitation means the precipitation until emergency of the maximum hourly precipitation of precipitation at the time of occurrence, and when there is no rainfall for over successive 4 hours, the rainfalls before and after such suspension were regarded to be separate continuous rainfalls.

The continuous rainfall was also limited so that it would not exceed 24 hours. In Figure 3-5 ~ 7, only the rainfalls of a maximum hourly precipitation of 5 mm or more and a continuous precipitation of 10 mm or more are plotted.

Now, the mudflow of this summer may be said to have occurred, as compared with those in the past years, with a rainfall of a relatively small scale. According to the survey of snowfall conducted by the Tokyo Electric Power Co. in the vicinity of Kamikochi, the snow of this spring (1974) is not much different, as of March 24, from that in the last year. But, taking the snowfalls of these two years at about April 20, this year is greater than the last year by about 20 cm in the depth of snow and about 130 mm in the snow water (upon the data at 40 points of measurement). Additionally, the temperature this summer was lower than the average so that there was the remaining snow present under the sediment deposited on the valley bed not only until later time but in a greater quantity than in the usual years. Thus, it is considered that this layer of remaining snow forms an impermeable layer for the water of infiltration so that the sediment fed from the valley walls and deposited on the layer of remaining snow is readily fluidized with a relatively small heavy rainfall and causes small mudflows to occur frequently.

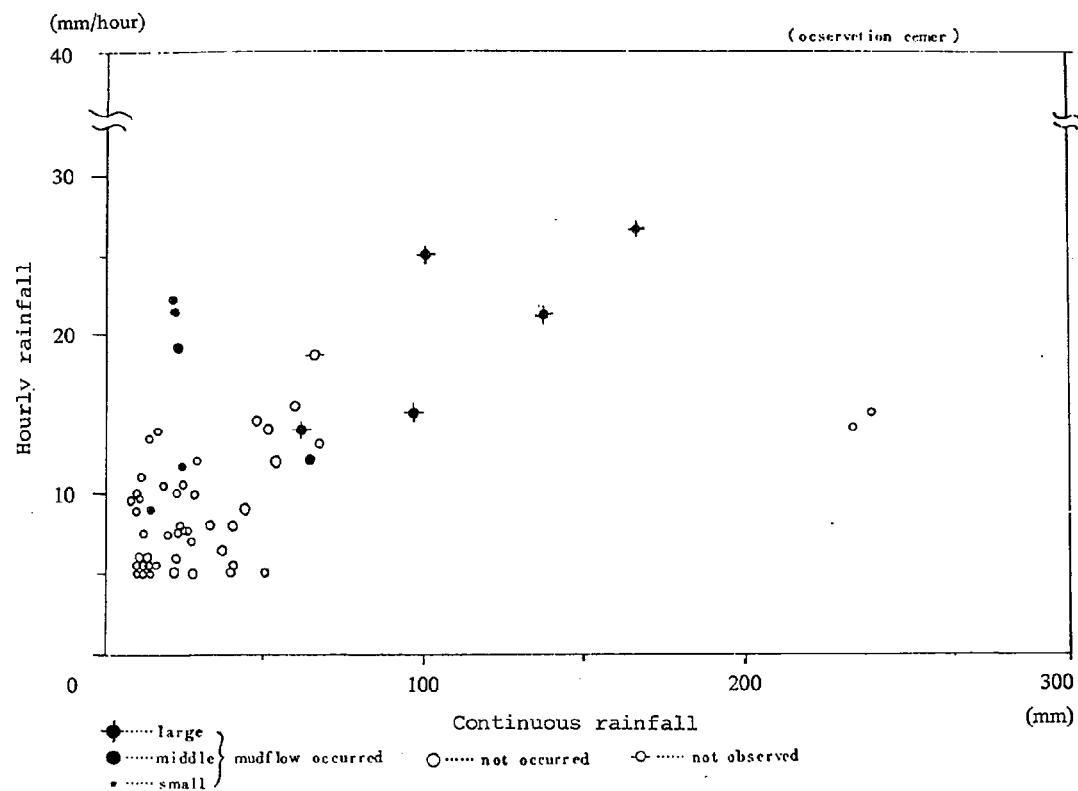


Fig. 3-5 Rainfall Condition and Mudflow Occurrence

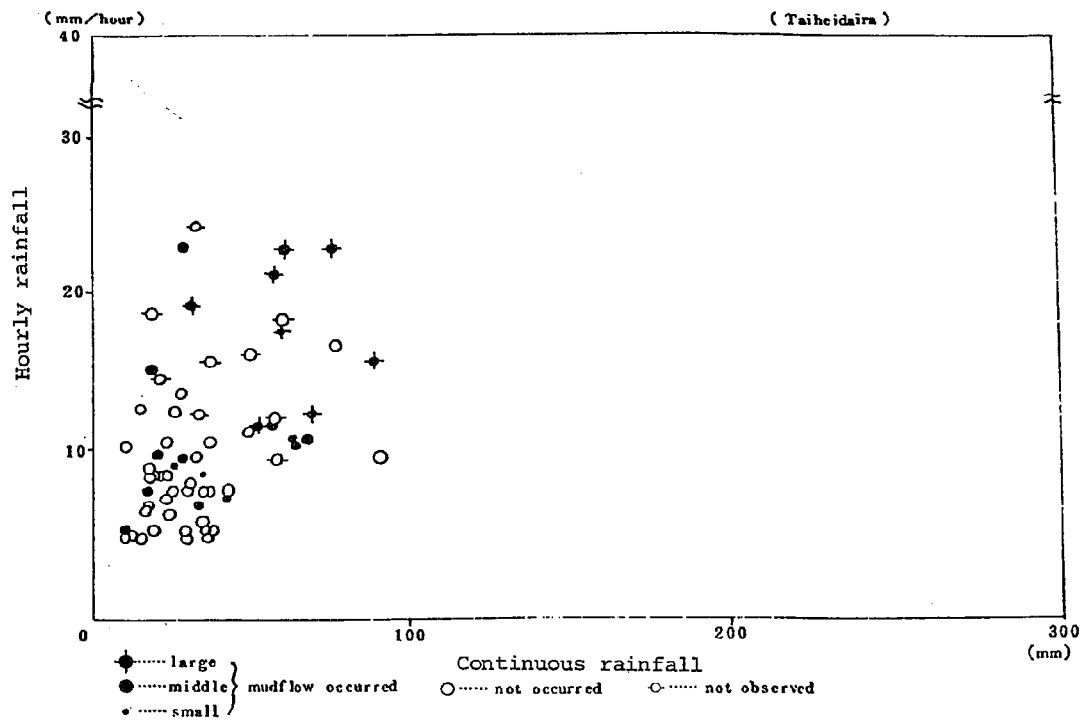


Fig. 3-6 Rainfall Condition and Mudflow Occurrence

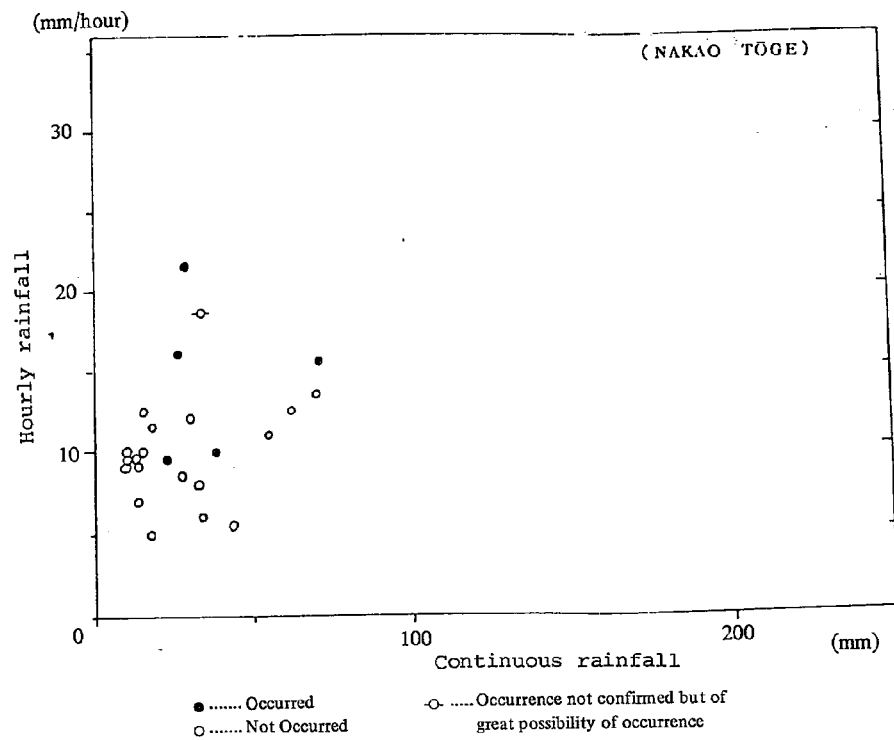


Fig. 3-7 Rainfall Condition and Mudflow Occurrence

It should be noted that these data represent those in a particular area at the base of an active volcano. For the sake of comparison, data showing a national trend of occurrence of mudflows are cited below.

¹⁾ Katsumi Seo and Masatsugu Funazaki: Damage by debris and Precipitation, Shin-Sabo 89, Nov. 1973.

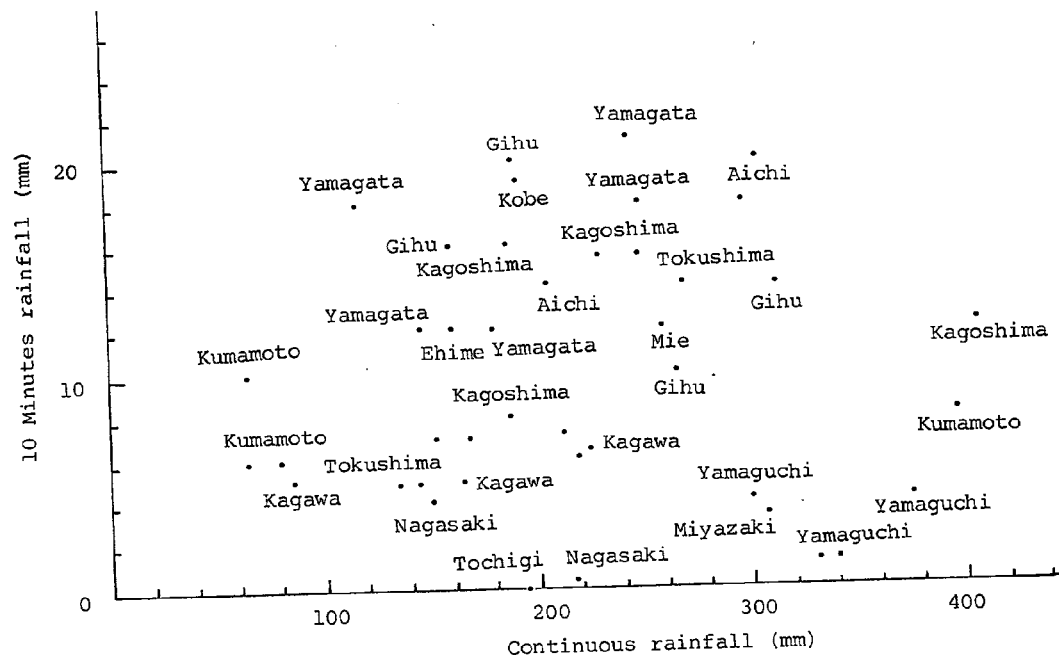


Fig. 3-8 Continuous Rainfall up to Occurrence of Mudflow Versus 10 Minutes Rainfall at Time of Occurrence. ¹⁾

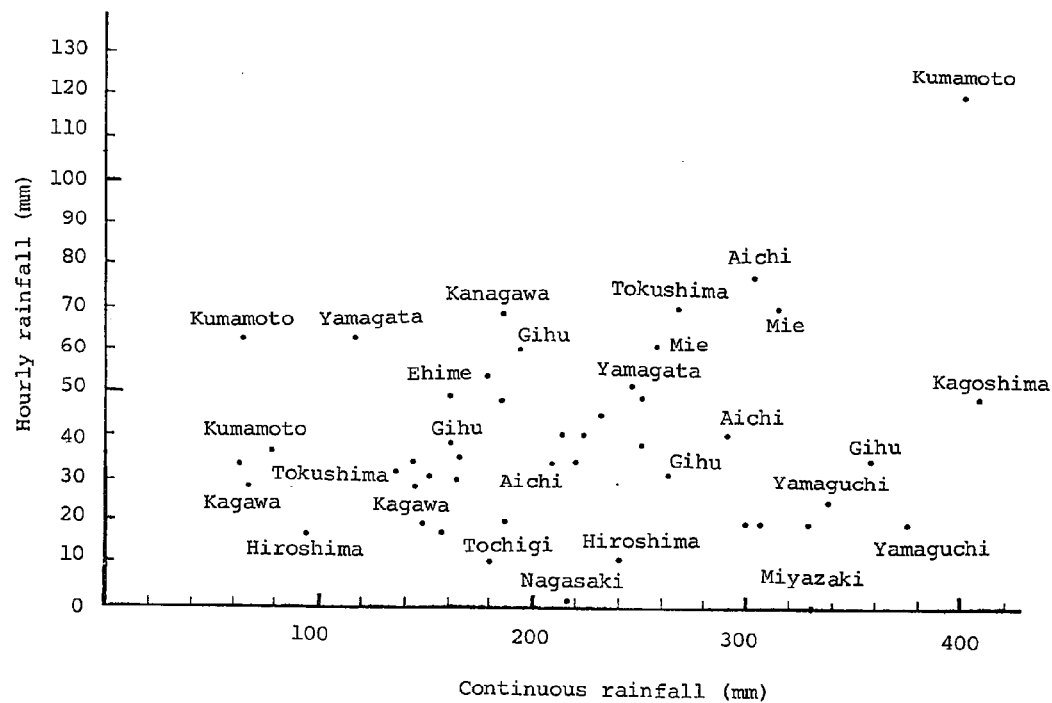


Fig. 3-9 Continuous Rainfall up to Occurrence of Mudflow
Versus Hourly Rainfall at Time of Occurrence. ¹⁾

These diagrams provide valuable suggestions with respect to the total rainfall and rainfall intensity required for generation of a mudflow. However, the authors of the diagrams commented that the diagrams showed only the rainfall phenomenon that the rainfall of greater continuous precipitation was also greater in the rainfall intensity.

4. RECORDS OF THE FORMS OF FLOW OF MUDFLOWS

To take the pictures of the forms of movement of mudflows is one of the largest objectives of the mudflow observation. But, because of a fog or rain at the time of occurrence of a mudflow or shortage of light should a mudflow occur at night, it is very difficult to obtain sharp and clear pictures.

As the result of observation over long years, we could obtain the best pictures throughout the past six years with an 8 mm cinecamera on July 13, 1975 and V.T.R. on August 23 of the same year. This mudflow (July 13) was of a relatively small type of silt and gravel composition as it was preceded by three waves of mudflows which rushed out a great quantity of sediment deposit on the valley bed. The state of the mudflow of July 13 flowing over the No. 7 groundsel in the Kamikamihori Valley is shown in continuous still pictures.

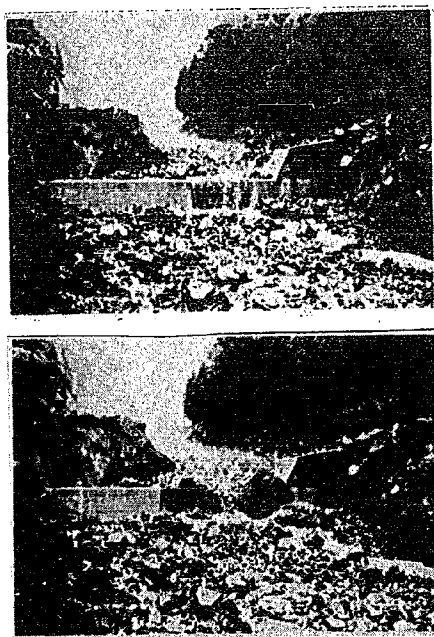


Photo 4.1



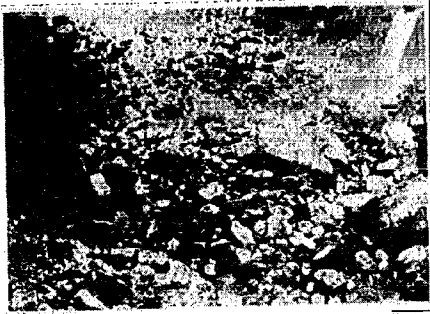


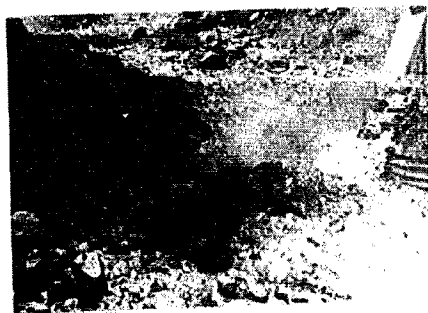
Further, it was a dream over a long period of time to take pictures of the leading part of a dynamic mudflow with a camera of good resolution, and we succeeded in taking continuous 250 frames of pictures, 1 frame per second, with a 35 mm motor-drive camera on August 3, 1976. In photos are shown this mudflow as it overflows the bed compaction up No. 6 in the Kamikamihori Valley.

It may be seen from the 250 frames of pictures (1) that the leading part is elevated in the form of an abrupt wave, (2) that larger stones gather at the leading part to present a state of stone flow with little water at the extrem front portion, (3) that because of inertia, the mudflow swells, as it runs, toward the outside of a curve along the path of flow, (4) that the mudflows contain a number of large stones with mass concentrated only for several tens seconds during which the leading part passes and the subsequent flow presenting a state of mud paste which attenuates gradually and (5) that from the scattering condition of gravels shown on the pictures, there is a distribution of velocity in the transversal direction, the velocity being great near the center of flow and often reduced extremely near the banks. From (5) above, it is presumed that the mudflow presents macroscopically a behavior similar to a Bingham plastic (when shear stress exceeds yielding shear stress strain rate is produced).



Photo 4.2





5. SPEED OF LEADING EDGE OF MUDFLOW

5.1 Results of Observation

With a number of sensors arranged along the path of a mudflow and by measuring the time of passage and distance between two adjacent sensors, there is obtained the mean speed in the section. The values of speed thus obtained are shown in a profile of the valley. As seen, the speed is fast in the upper parts and is reduced gradually toward the lower parts. But, in the lower parts, the mudflow has the speed accelerated as it passes over steep slopes. Thus, it is known that the influences of slope and width of the flow course must be taken into consideration.

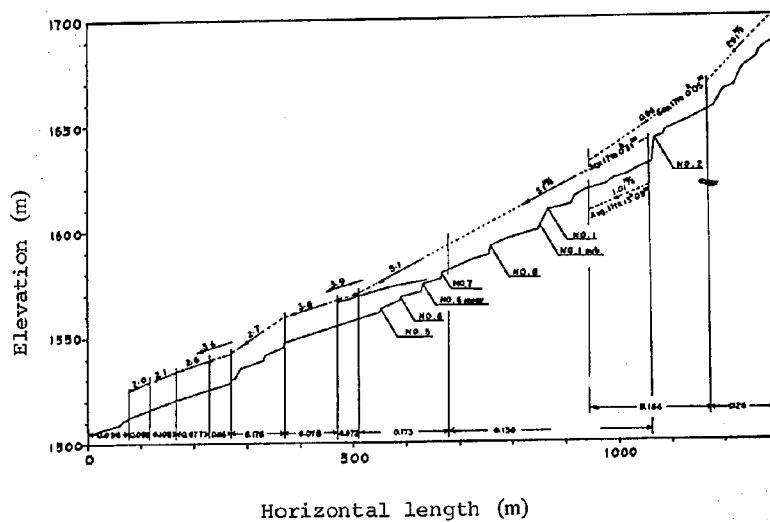


Fig. 5-1 Mudflow Speed Distribution Diagram (Occurring in Kamikamihori Valley, September 17, 1972)

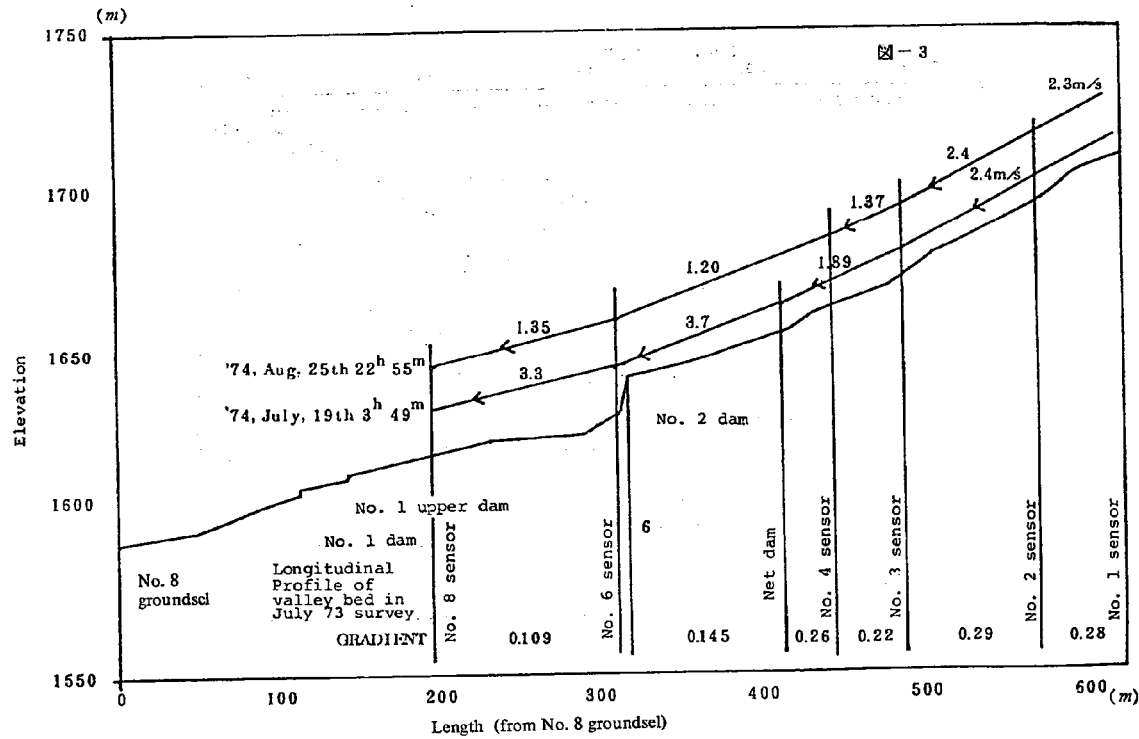


Fig. 5-2 Mudflow Leading Edge Speed and Logitudinal Profile of Valley Bed (Kamikamihori Valley)

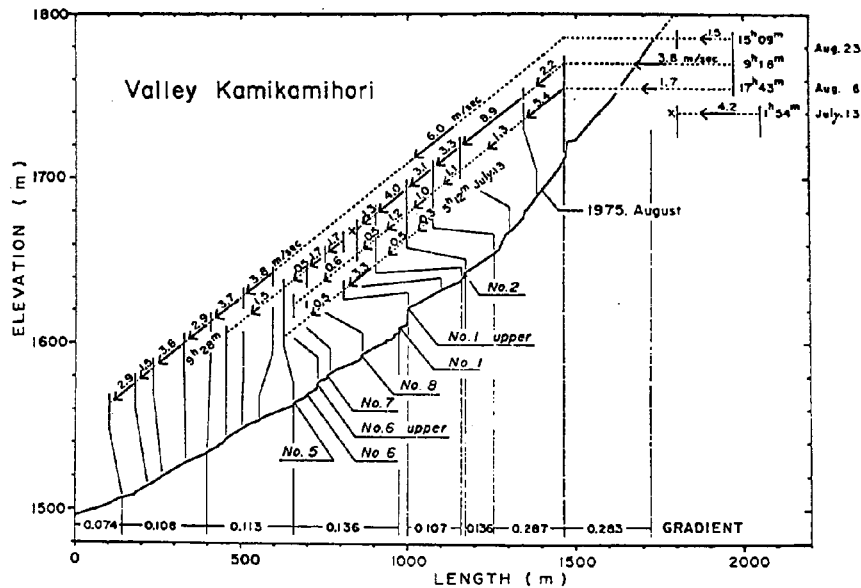


Fig. 5-3 Kamikamihori Valley Bed Longitudinal Profile and Mudflow Leading Edge Speed

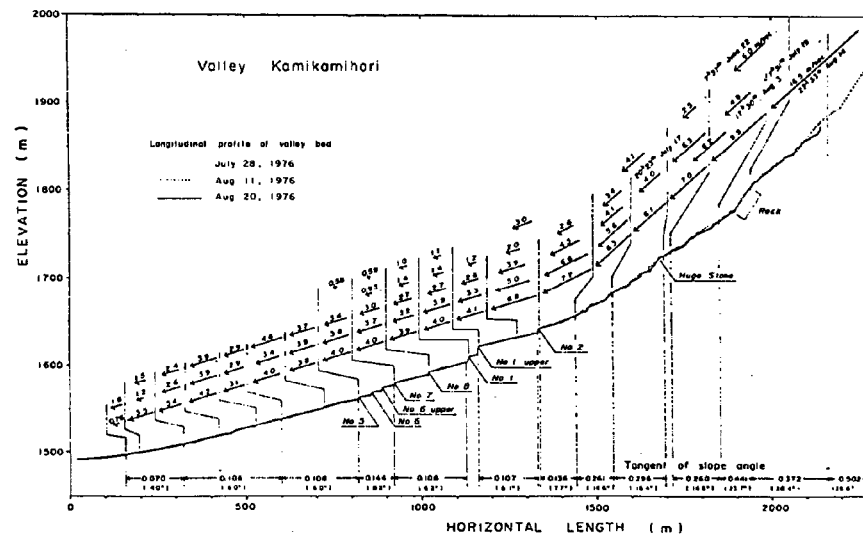


Fig. 5-4 Change in Leading Speed of Mudflow and Kamikamihori Valley Bed Longitudinal Profile

5.2 Approximate Analysis of Motion on Slope

Since the front portion (head) of the mudflow flows while gathering earth and gravel in the upstream erosion area and flows while dropping them in the downstream deposit area, changes in mass of the raised head portion cannot be avoided. However, it will be analyzed below by the mass point dynamic for first approximate analysis ignoring the change in mass. (Reported by Okuda and others in the convention of Disaster Prevention Research Institute of Kyoto University on Feb. 7, 1973)

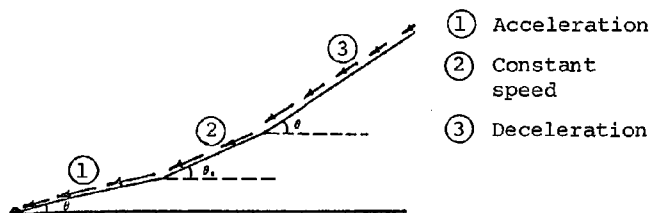


Fig. 5-5 Schematic Drawing of Mudflow Motion

If moving distance on slope is x , velocity is $\frac{dx}{dt} = \dot{x}$, acceleration is $\frac{d^2x}{dt^2} = \ddot{x}$, angle of slope is θ , coefficient of dynamical friction is μ , drag coefficient is k , mass of raised portion of mudflow is m , and gravitational acceleration is g , then component in the downstream direction on slope is $mg \sin \theta$ and component in the upstream direction is $\mu mg \cos \theta + kx^2$. Thus acceleration can be given by

$$\ddot{x} = g(\sin \theta - \mu \cos \theta) - kx^2 \quad (2)$$

$$\text{where } A = g(\sin \theta - \mu \cos \theta) \quad (3)$$

5.2.1 Acceleration Area

$A > 0$ if θ is large ($\theta > \tan^{-1} \mu$). If it starts from still condition ($\dot{x} = 0$ at $t = 0$), it is gradually accelerated when $\ddot{x} > 0$, and velocity $v (= \dot{x})$ gradually approaches to a constant velocity $v_f = \sqrt{A/k}$.

Velocity;

$$v = v_f \tanh(v_f k t) \quad (4)$$

Final velocity;

$$v_f = A/k \quad (v \text{ at } t \rightarrow \infty) \quad (5)$$

Flow distance

$$x = \frac{1}{k} \log_e \cosh(v_f k t) \quad (6)$$

Velocity in upper reach was not actually measured so that it can be assumed as $v_f = 6$ m/sec from the maximum value actually mean angle of slope $\theta = 17^\circ$ in upper stream and drag coefficient $k = 0.005/\text{m}$ (assumed from example described later), $A = 0.018 \text{ m/sec}^2$ from equation (5) and $\mu = 0.30$ from equation (3).

v will gradually approach to v_f through an infinite distance but flow distance $x_{0.90}$ required to reach to 90% of v_f can be given by $x_{0.90} = 1,650$ m from values shown above by using equations (5) and (6).

Actual flow distance was 1,200 m so that more distance may be required in order to approach the velocity to v_f . It may be said that the mudflow moved to more gentle slope in this condition in the Kamikamihori Valley.

5.2.2 Constant Velocity Area

The head of mudflow accelerate in upper reach will have velocity v_e and more to gentler slope (angle θ_e) where the velocity v_e is $\sqrt{Ae/k}$. However, motion with constant velocity will be continued at $x = 0$ if condition of $Ae = g(\sin \theta_e - \mu \cos \theta_e)$ is met.

If area to No. 1 dam is assumed to meet this condition by the measurement in the Kamikamihori Valley, then $v_e = 5.1$ m/sec and $\theta_e = 7^\circ 41'$. If $k = 0.0005/\text{m}$ shown above is used here, then $Ae = 0.0125/\text{sec}^2$ and $\mu = 0.134$.

5.2.3 Deceleration and Stop Area

If mudflow move again to gentler slope ($\theta < \tan^{-1} \mu$) in lower reach, then $A < 0$ and it will finally stop after deceleration.

If mudflow moves to this gentler slope at $t = 0$, the flow distance x as derived from equation (2) with $x = 0$ and $v = v_0$ (initial velocity) can be given by

$$x = \frac{1}{2k} \log_e \frac{kv_0^2 + |A|}{kv^2 + |A|} \quad \dots \dots \dots (7)$$

where $|A| = (\mu \cos \theta - \sin \theta)$

Flow distance l travelled until it stops is derived from equation (7) with $v = 0$ and expressed by

$$l = \frac{1}{2k} \log_e \left(1 + \frac{kv_0^2}{|A|} \right) \quad \dots \dots \dots (8)$$

(run-out distance)

If area from No. 5 dam to lower reach in the Kamikamihori Valley is assumed to meet this condition, $l = 550$ m will be obtained. The combination of k , $|A|$ and μ which will satisfy the equation (8) was then calculated using mean angle slope of $\theta = 4^\circ 47'$ in the area as indicated in Fig. 23.

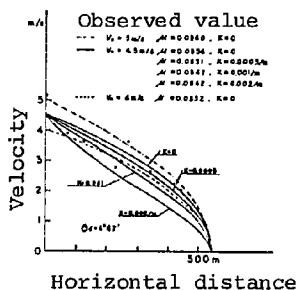


Fig. 5.6 Relationship Between Horizontal Distance and Velocity Reducing

However, only the values within certain limit in the combination were indicated in the figure. For initial velocity v_0 , actually measured value of 5.1 m/sec was not used and a value slightly smaller than this was used since energy loss at the slope transition point was taken into consideration.

By using these values the relationship between flow distance and velocity reducing in the area has been expressed by curves. When comparing the results to the measured values (shown by "O"), the actual conditions are well expressed when $\mu = 0.0842$ to 0.0860 and $k = 0.0005/$ to $0.001/m$.

Equations (7) and (8) can be expressed by the following equations if approximate equation $\log_e (1 + y) = y$ (where $y \ll 1$) is employed when $kv_0^2 \ll |A|$:

$$x \doteq (v_0^2 - v^2)/2|A| \quad \dots\dots\dots (7')$$

$$l \doteq v_0^2/2|A| \quad \dots\dots\dots (8')$$

These results will coincide with those obtained from elementary dynamics. If k is less than $0.001/m$, approximate tendency may be expressed by these approximating equations. Value of μ is very close to $\tan \theta = 0.0837$ for the values in this extent and value of $|A|$ will greatly change if μ varies slightly so that value of μ must be carefully selected when computing l .

Also value of coefficient of dynamical friction μ varies such as 0.30 in upper reach, 0.134 in middle reach and 0.085 in lower reach. This occurs because abrasion condition between raised portion of mudflow and levee of torrent may vary depending upon the location. (Side abrasion is high due to narrow width of torrent in upper reach but no side force is applied in lower reach since mudflow runs through wide swamp.)

The 1st dimensional analysis described above may be impractical if front edge of the mudflow thinly widened in fan in lower reach but it can be used for approximation in this particular case where it was not widened in lower reach as observed from the distribution of the large gravel.

If limit of values of μ and k is clarified as a result of many on-site measurements in the future, the extent of the travelling distance of the mudflow can be forecasted.

6. HYDROGRAPH OF MUDFLOW

For preparing an accurate hydrograph of a mudflow, it is required to measure the mean speed and changing cross-sectional area of the flow from time to time. But, the observation of the former is very difficult, and in the observation of this year, we were unable to measure even the surface velocity.

Meanwhile, we succeeded in 35 mm frame photographing of the mudflow occurred on August 3, 1976. From the pictures, it is possible to read the cross-sectional area, height, hydraulic radius, etc. of the flow when it flows over No. 6 upper groundsel (Fig. 6-1).

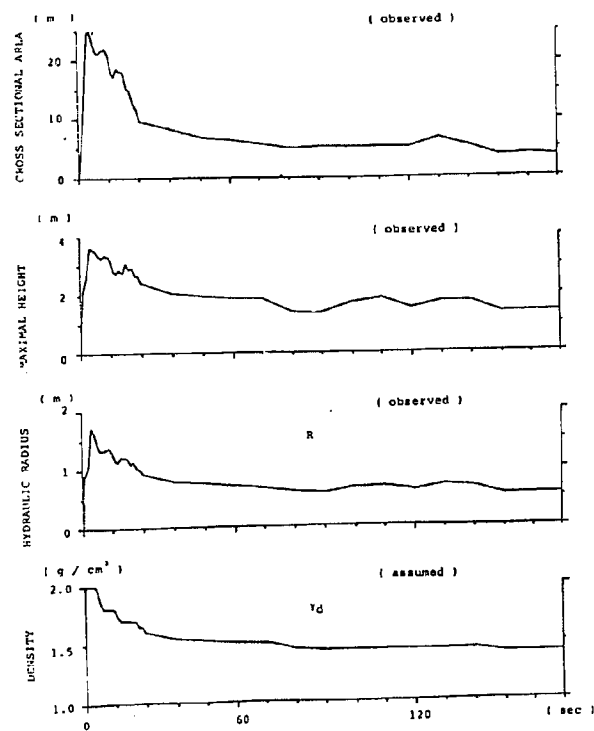


Fig. 6-1 Cross-sectional Area, Height, Hydraulic Radius
Estimated Density of the Mudflow at No. 6.

With these values and the leading edge speed at 3.8 m/sec as clues, we tried to prepare a hydrograph of the mudflow. Presently, there is no rule of drag nor formula of flow established definitely for the mudflows. Here, thus, for calculation of the mean speed of the mudflow, three separate methods of (1) Daido's drag rule concerning mud slurries¹⁾, (2) Manning's equation for the velocity of uniform flow^{2), 3)} and (3) Stribniy's equation for the velocity of mudflows⁴⁾ were employed.

In the calculations, the following symbols are used, viz. U : Mean velocity; U_* : Frictional velocity; B : Hydraulic radius; I : Gradient of slope; f_B : Drag coefficient; k : Equivalent roughness; τ_0 : Bottom shear stress; γ : Density; n : Equivalent to Manning's roughness factor; V : Dynamic viscosity coefficient; and g : Gravity acceleration.

[Daido's Drag Rule for Mud Slurries]

Daido tested flow of a mud slurry under turbulent condition in a rough surfaced open channel and obtained the following formula to express its drag

$$\frac{1}{\sqrt{f_B}} = 4.2 + 4.07 \log \frac{R}{k} \quad \dots \dots \dots (6-1)$$

where f_B is a drag coefficient to be introduced by the formula of definition

$$\tau_0 = \frac{1}{2} f_B \gamma U^2 \quad \dots \dots \dots (6-2)$$

Then,

$$\frac{\tau_0}{\gamma} = gRI \quad \dots \dots \dots (6-3)$$

Therefore,

$$U^2 = \frac{2gRI}{f_B} \quad \dots \dots \dots (6-4)$$

Now introducing $U = 3.8$ m/sec as the initial velocity and the values of I and R to determine the drag coefficient f_B , then the value of f_B thus determined and that of R are used in formula (6-1) to determine the equivalent roughness k . If the value of k is constant, the value of f_B changing from time to time is obtainable by substituting R in formula (6-1) with the value of measurement. By substituting such f_B in formula (6-4), the mean velocity is obtainable, and by multiplying U by the cross-sectional area of the flow, the discharge at any time is obtainable. The curves of velocity and discharge thus obtained are shown at the top in Fig. 6-2.

- 1) Katsumasa Yano: "Science of Water Disasters", Gihodo, 1971, pp. 442-447.
- 2) Koji Takahashi: Dynamic Aspects of Flood Abrupt Waves in Ripid Rivers, Brochure of Papers at the 8th Symposium on Science of Natural Disasters, 1971, Sapporo, pp. 91-92.
- 3) A.E. Scheidegger: Physical Aspects of Natural Catastrophes, Elsevier, 1975, p. 147.
- 4) Goldin, B.M. and Lyubashevsky, S.L.: Computation of the velocity of mudflows for Crimean rivers, Soviet Hydrology, 1966, vol. 2, pp. 179-181.

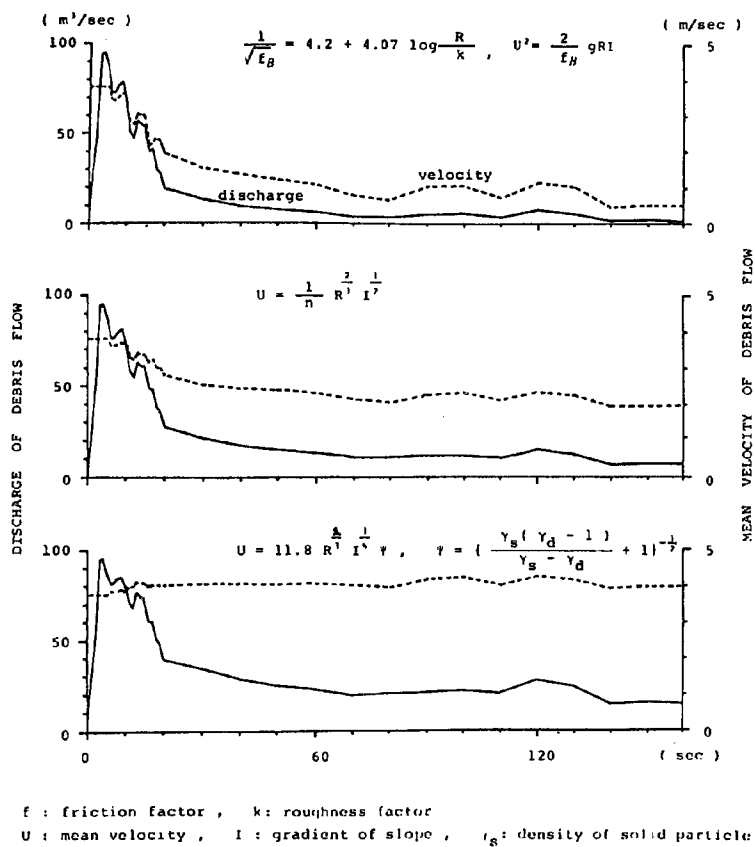


Fig. 6-2 Calculations of the Velocity of Mudflow and Hydrographs
(Mudflow No. 6 running down the No. 6 upstream groundsel)

[Manning's Equation for the Velocity of Uniform Flow]

Takahashi²⁾ and Scheidegger³⁾ noted that for expression of the velocity of mudflows, a formula of the same form to Manning's equation for the velocity of uniform flow would agree relatively well with the data of measurement. Thus, heretere was used a formula of the same form to the Manning's equation, or

$$U = \frac{1}{n} R^{2/3} I^{1/2} \dots\dots\dots (6-7)$$

The gradient of slope I of the site is 0.107.

First, for the initial velocity, using the data of measurement for U and R at the leading part, there was contained $n = 0.109$ (greater than the maximum value of $n = 0.07$ listed in the usual numerical tables). Then, the value of U was determined from formula (6-7) in a manner similar to that according to the method described in the preceding paragraph. Thus, there was obtained a graph shown at the middle in Fig. 6-2.

[Stribniy's Velocity Equation]

Stribniy of Soviet Russia modified the Chézy's formula for the velocity of uniform flow and gave the formula

$$U = 6.5 R^{2/3} I^{1/4} \psi \dots\dots\dots (6-8)$$

where ψ is a factor expressed by γd (density of mudflow) and γs (density of solid particles) as

$$\psi = \left\{ \frac{\gamma s (\gamma d - 1)}{\gamma s - \gamma d} + 1 \right\}^{1/2} \dots\dots\dots (6-9)$$

His formula is characterized in that the velocity is expressed as a function of the density (and, accordingly, concentration) of mudflows. Here, it was assumed that the density of solid particles would be 2.5 g/cm³ and that the density of mudflow would be decreasing from 2.0 g/cm³ (at the leading part) to 1.4 g/cm³ (after 160 seconds) in proportion to the hydraulic radius (without increasing R if there was any section where R tended to increase) (bottom in Fig. 6-1). Using such a value of γd and changing the coefficient of formula (6-8) to 11.8 so that it would conform to the initial velocity $U = 3.8$ m/sec, the mean velocity U was calculated. Thus, there was obtained a graph shown at the bottom in Fig. 6-2.

This method features in that U continues to hold a relatively large value. As seen from Fig. 6-3, the velocity changes little so that the mudflow in this case maintains its form, if there is no change in the mass, and continues to flow as a whole.

As described above, hydrographic analysis of the mudflow was thus made according to the foregoing three methods. But, in fact, the same mudflow was successfully taken in VTR. The video pictures were not of good resolution, but it was known that the mudflow had its surface velocity reduced nearly by half 160 seconds after it flowed over the No. 6 upper groundsel. From such point, the second method or Manning's equation seems to be best adapted for calculation of the velocity of mudflows.

According to this method, about 40 percent of the runoff of 3,000 m³ during the period of 160 second as shown in the graph is concentrated in about first 20 seconds after the mudflow runs down the No. 6 upper groundsel. That is, the form and mass as a mudflow are concentrated, in this case, in the first 20 seconds

(or, as a length of mudflow, about 76 m).

7. GRAIN SIZE DISTRIBUTION AT THE LEADING PART

Among the pictures 4-2 of the mudflow (occurred August 3, 1976) overflowing the No. 6 upper groundsel as referred to in the foregoing section, the six (6) pictures permitting reading of the gravel size were taken to obtain the gravel size distribution in the leading part. Of each of these six pictures, the maximum diameter of the respective stones exposed on the surface of that part of the mudflow which faced the camera as it flowed down the No. 6 upper groundsel was read. In consideration that a substantial part of the respective stones would be submerged in the mud water, the maximum diameter was taken as the mean diameter of the respective stones. The values of reading were dully corrected for difference in the magnification depending on the distance, and thus the real gravel size was calculated. The sizes thus calculated are shown as a frequency distribution per second (each picture) in block graphs of Fig. 7-1).

Gravels of a size smaller than 10 cm were rejected in that they would involve a great error. In the respective pictures, the gravels within the read portion were changed completely so that there was no possibility of reading the same stone repeatedly. A total distribution of the gravel sizes that could be read during six seconds after the leading edge of the mudflow passed over the No. 6 upper groundsel (corresponding to that portion of the leading part which is about 20 m from the leading edge) is illustrated in Fig. 7-2.

Further, regarding the gravels as a spherical body having the respective diameters, there were obtained cumulative weight percentages from the frequency distributions as shown by a curve in the respective graphs. As seen, there is a great scattering in the distribution in the cross-section of the respective times.

It may also be seen from Fig. 7-2 that the central gravel size was 110 cm which the maximum gravel size was about 300 cm as a whole.

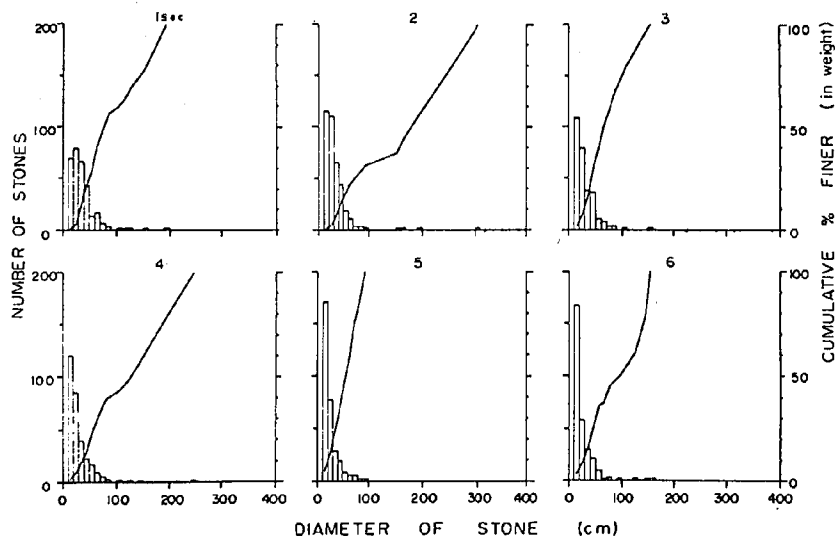


Fig. 7-1 Gravel Size Distributions in the Leading Part of the Mudflow as Read from Pictures 4-2 (per second)

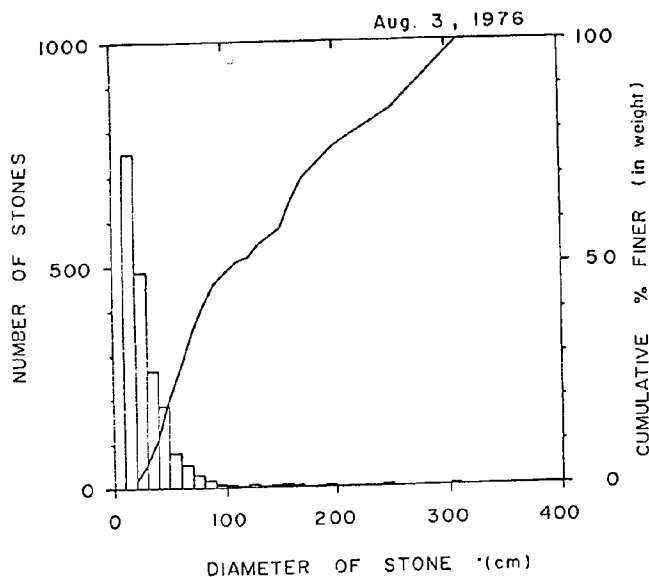


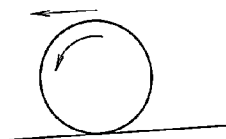
Fig. 7-2 Gravel Size Distribution in the Leading Part of the Mudflow (6 seconds)

8. MOTION OF BOULDERS AT THE LEADING PART OF MUDFLOW

The mudflow (occurred August 23, 1975) we succeeded in taking VTR pictures was a typical type of the mudflows occurring on Mt. Yake and had a number of large gravels gathered and moving vehemently at its leading portion. Taking six large gravels the motion of which could be read accurately, their respective kinetic energies and momentums were calculated in the translating and rotating components. The results are shown in Fig. 8-1. In reality, the large gravels presented themselves an indefinite form but were assumed to be a spherical body respectively for the sake of calculation, and the motion was calculated approximately with the mean diameter used. Here, the "constrained" (affix c) means that there is no slip at the point of contact of the slope and the spherical body.

From the results, it may be said (1) that the direction of rotation of any large gravel is in match with that of natural rolling, (2) that the rotation actually occurring is either faster (jump type) or slower (sliding type) than that without slip and (3) that the kinetic energy is shared nearly equally by the translating and rotating components (the difference being in the order of one digit at the largest).

Gravel No.	Mean diameter	Mass	Angular velocity	Constrained angular velocity	Kinetic energy			Momentum		
					Trans- lation	Rota- tion	Const- rained rotation	Trans- lation	Angular	Const- rained angular
	l	M	W	Wc	Ek	Er	Erc	M	Mr	Mrc
	m	ton	sec ⁻¹	sec ⁻¹	ton m ² /sec ²			ton m/sec	ton m ² /sec	
1	2.4	16.9	1.4	3.1	116	10	46	63	13	7.4
2	2.3	15.7	2.9	3.2	107	34	43	58	24	6.7
3	3.3	46.7	Illegible		316			171		
4	1.3	2.9	7.9	5.7	20	15	8	11	4	0.7
5	2.0	10.1	10.4	3.7	70	218	28	38	42	3.7
6	2.4	16.9	Stoppage							



Assumption: Motion of spherical body

$$v = 3.7 \text{ m/sec} \quad \rho = 2.5 \text{ ton/m}^3$$

$$M = \rho \frac{4}{3} \pi \left(\frac{l}{2}\right)^3 \quad I = \frac{2}{5} M \left(\frac{\rho}{2}\right)^2$$

$$Er = \frac{1}{2} I W^2 \quad Mr = I W$$

Fig. 8-1 Motion of Large Gravels (August 23, 1975 at 15:09 hours)

9. IMPACT FORCE OF MUDFLOW

In design of a structure intended to stand against a mudflow, the intensity of the impact force of mudflow will be the most important problem.

In the following are shown the results of measurement and the locations of installation of pressure mark gauges in the years of measurement.

Impact Force Measurement Results

Pressure mark gauge No.	Maximum impact force as converted (to weight)	Leading edge speed of mudflow
1	0.7	5.1
2	1.0	
3	0.3	
4	1.4	
5	6.0	
6	2.1	3.3
7	1.1	
8	3.3	2.7

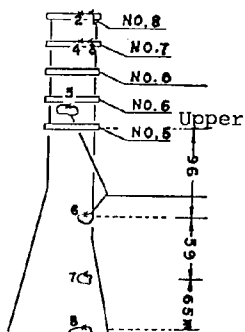


Fig. 9-1 Arrangement of Pressure Mark Gauges

Data of Pressure Mark Gauge

plate area: 15x15 cm²

Pressure mark gauge No.	Maximal impact force estimated from pressure mark (ton-weight)	Front velocity of debris flow (m/sec)
1	0.18	about 6.0
2	0.07	
3	0.08	
4	4.84	
5	1.48	about 3.8
6	0.77	
7	0.68	
8	0.88	3.7
9	0.86	3.3

9: July 13, 1975; 1 ~ 8: Aug. 23, 1975

X Setting position of pressure mark gauge

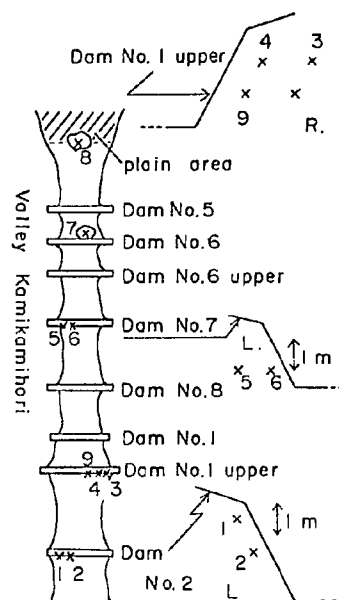


Fig. 9-2 Impact Force of Mudflow Noted on Pressure Mark Gauge

Date of Pressure Mark Gauge

1976

Date	gauge No.	Maximal impact force estimated form gauge (ton-weight)	Front velocity of debris flow (m/sec)
July 19	1	0.81	2.6
	3	2.33	3.0
	4	0.41	
	5	2.19	3.4
Aug. 3	2	0.49	5.0
	3	0.38	3.7
	4	0.55	

X Location of gauge, plate area: 15x15 cm²

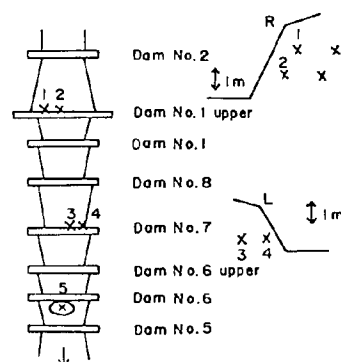


Fig. 9-3 Pressure Mark Gauge Installed Locations and Mudflow Impact Force

In the Last

The results of observation of the mudflows on Mt. Yake and those of analysis of some phenomena have been introduced in the foregoing. The author feels that through these observations and researches, our knowledge on the actual behaviors of mudflows has made a remarkable advance.

Here, the author wish to express his appreciation for the researches and engineers of the Disaster Prevention Research Institute of the University of Kyoto as well as the Matsumoto Work Office of the Ministry of Construction who have carried out the difficult observations uninterruptedly, accumulated valuable data steadily and resourcefully and released them in the form of reports.

The mudflows, although they are simply so referred to, take various forms, and this is clearly shown in the recommendation on the mudflows of Sakurajima. It should, therefore, be noted that the phenomena which the results of observation at Mt. Yake show us do not represent all of the mudflows. In order to establish our common concept for the term "mudflows", it will be necessary to accumulate the data on the mudflows of various types one by one.

ii) Mudflows on Sakurajima Island and its Investigations

Masakiyo Tawara*

INTRODUCTION

Sakurajima Island is an existence that is sort of symbolic of Kagoshima Prefecture. The imposing shape of the mountain and the volcanic "smoke" as well as the beautiful sunset glow over the Kinko Bay never fail to fascinate the people living or visiting this place.

On the other hand, however, the residents on this island feel the menace of the very active volcano, damage caused by the fall of volcanic ash and also by the frequent occurrence of mudflows induced by the deposited ash.

In 1974 there occurred disastrous mudflows on this island, sacrificing eight persons. As a result it was strongly desired that adequate erosion control works would be undertaken under the direct jurisdiction of the Ministry of Construction. In 1974 the Kyushu Regional Construction Bureau created the technical committee for the prevention of disasters on Sakurajima Island including men of learning and experience and since then it has been making investigations and disaster preventive programs. This paper is devoted to a brief description of such activities.

* The Ibusuki River Works Office, Kyushu Regional Construction Bureau, the Ministry of Construction.

1. A BRIEF DESCRIPTION OF SAKURAJIMA ISLAND

Sakurajima was once an island lying in the bay of Kagoshima, the flow of lava in the great volcanic eruption of 1928 choked up the narrow channel of water which separated it from the Osumi Peninsula.

Sakurajima is roughly circular in shape and has an area of about 80 km². At the center of the island are three volcanic mountains, Kitadake (Northern Peak), Nakadake (Middle Peak) and Minamidake (Southern Peak, 1,040 m, still very much active, emitting clouds of steam) rising side by side roughly from north to south. Up to 400 to 500m above sea, the island consists of ancient deposits of volcanic eruptions which form the three peaks with their slopes having the average inclination of 20-odd degrees. Down to 200 ~ 100 m above sea are distributed the deposits of volcanic materials which were ejected after the beginning of the recorded history, having their surfaces sloping at angle of about 20 degrees. The newer solidified lava forms lava fields extending to the coasts various places. In other areas below 200 to 100 m are gentle slopes of hillsides with an inclination of less than 5 to 10 degrees on the average or sloping alluvial fans. Covered with many strata of pyroxene and site lava flows, homogeneous pyroclastic material, pumice, and volcanic ash, the mountainsides are extremely susceptible to gully erosion.

The areas higher than 700 ~ 800 m are virtually bare of vegetation while the lower slopes are increasingly covered with grass and vegetation. There are many small gullies on the bare mountainsides and they merge as they come down and form large and deep tree-shaped valleys and further extend downward in the form of U-shaped valleys running through forests to reach the gently sloping areas at 200 ~ 100 m. The areas lower than the 200 ~ 100 m zone are highly utilized for farms, orchards, residential land, tourist resorts and plantation.

About 11,000 people are living on the island with about 20 km² of arable land, engaged in agriculture such as the growing of tangerines and medlars and Sakurajima radish. However, the livelihoods of the residents of Sakurajima are based largely on tourist business including the municipally operated ferry services.

About 85% of the island are included in the Kirishima-Yaku National Park and there are many tourist facilities, attracting as many as 2,300,000 tourists every year. With National Road No. 224 running through the lava field along the coastline to connect the city of Kagoshima and the Osumi Peninsula, Sakurajima is an important point of communication and transportation in this region.

2. VOLCANIC ACTIVITIES

Sakurajima has an active volcano belonging to the Kirishima volcanic zone. The ancient records say that the island came into being due to the upheaval of a submarine volcano in 708. Since that time a total of thirty-one eruptions were recorded until the big one in 1914.

Since the advent of the Showa era (beginning in 1927), the third phase of volcanic activity has been going on since 1972 with the first phase beginning with the ejection of lava in 1946.

It has been empirically known since a long time ago that is a close relationship between the eruptions and increased volcanic action of Sakurajima and the increased production to flow of earth and sand.

Table 1 Volcanic Activities

Year	Frequency of eruption	Frequency of smoke emission	Frequency of earthquake
1965	29	36	10,304
'66	44	225	17,077
'67	127	511	35,174
'68	87	351	30,384
'69	22	128	16,801
'70	19	355	18,264
'71	10	45	10,974
'72	108	485	31,956
'73	144	673	74,878
'74	362	1,226	122,805
'75	198	694	73,297

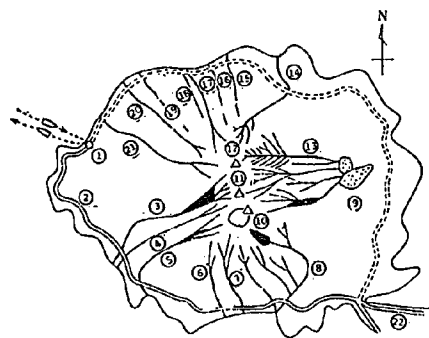
3. THE PRESENT STATE OF RIVERS ON SAKURAJIMA

Sakurajima has fifteen rivers, large and small, including the Nojiri River, and most of them originate near the mountain-tops and flow into the Bay of Kinko. (Fig. 1)

These rivers, narrow and steep, are normally dry. Eleven of the thirteen rivers were designated for the areas where erosion control work should be done and auxiliary erosion control works has been under way since 1964 and flood control afforestation has been carried out since 1962.

On the island of Sakurajima with such geological and topographical conditions, drastic longitudinal, lateral and surface erosions are in progress at all times in the areas higher than 400 ~ 500 m. When it rains the mud flows containing earth and sand flow down through the U-shaped valleys in the intermediate zone, behaving somewhat like earth and rock avalanches and wearing away the sides of valleys, and are released only when they reach the 200 ~ 100 m areas.

As seen from Table 1 showing the basin areas and total lengths, the rivers on Sakurajima are small in scale but have such characteristic features that they have vast sources of earth and sand, earth and sand flows are liable to occur quickly in heavy rains, and their gradients change so abruptly that the earth and sand are liable to cause flooding.



- | | |
|-----------------------------|------------------------|
| ① Hakamagoshi | ⑫ Kita-dake |
| ② National Road No.224 | ⑬ Kurokami River |
| ③ Nojiri River | ⑭ Kokara River |
| ④ Narumatsu River | ⑮ Amida River |
| ⑤ Mochiki River | ⑯ Matsuura River |
| ⑥ Daini-Furusato River | ⑰ Nishimichi River |
| ⑦ Daiichi-Furusato River | ⑱ Hanzuzono River |
| ⑧ Arimura River | ⑲ Nakatsuno River |
| ⑨ Jigokugawara alluvial fan | ⑳ Fukaya River |
| ⑩ Minami-dake | ㉑ Hase River |
| ⑪ Naka-dake | ㉒ National Road No.220 |

Fig. 1 Rivers and Landslides

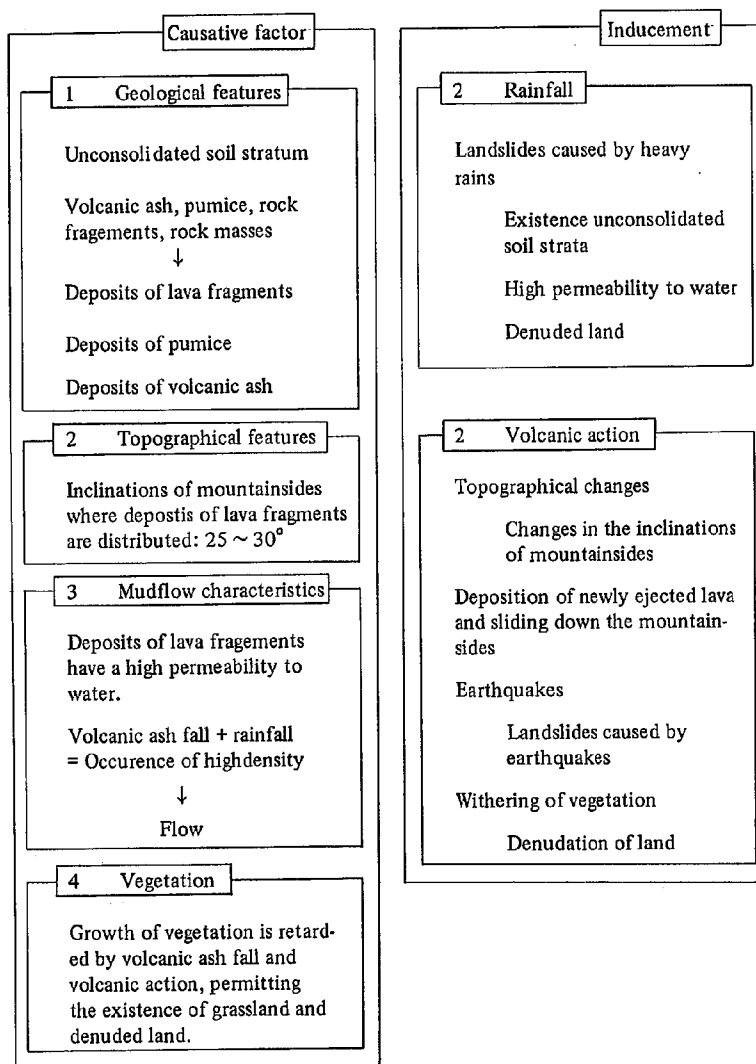
Table 2 Basin Areas and Total Lengths of the Rivers on Sakurajima

Name of river	Basin area (km ²)	Total length (km)
Nojiri River	2.99	5.4
Harumatsu River	2.09	4.3
Mochiki River	1.61	4.5
Daini-Furusato River	1.40	2.9
Daiichi-Furusato River	0.86	3.0
Arimura River	3.65	3.8
Kurokami River	9.80	5.9
Total	22.40	29.8
Kokara River	3.24	3.25
Amida River	2.94	2.75
Matsuura River	2.28	4.50
Nishimichi River	3.56	5.00
Hanbuzono River		
Nakatsuno River		
Fukaya River	3.55	3.50
Hase River	4.04	4.00
Total	32.39	24.00

4. NATURAL CONDITIONS AND DISASTERS

The causes for landslides can be classified broadly into the natural conditions (causative factors) and the causes closely related to them (inducements). The natural disasters on Sakurajima are characterized by the fact that volcanic action plays a very important role in inducing such calamities unlike in most of other districts. (Table 3)

Table 3 Causes for Landslides



It may be permissible to consider that the natural disasters on this island are all ascribable to mudflows.

Table 4 shows schematically the mudflow throughout the process of its generation, transportation and deposition, and the associated natural conditions.

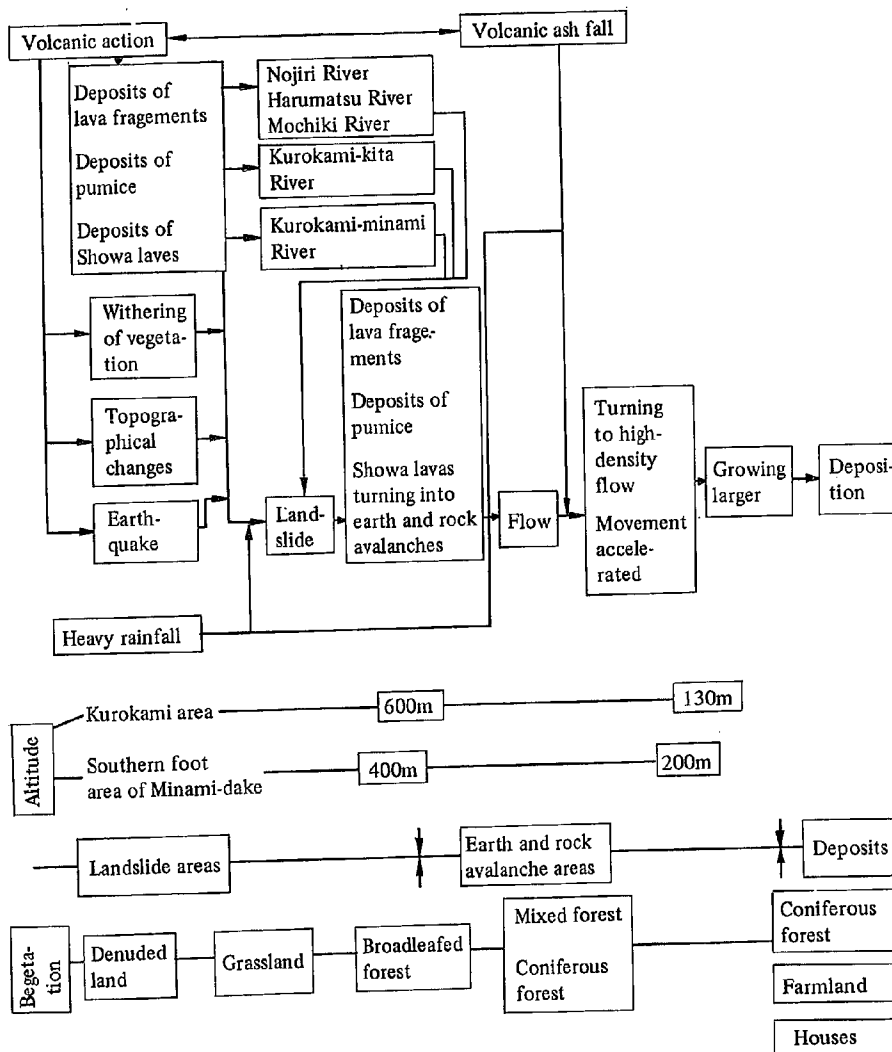
The landslides occur mainly on the slopes having an inclination of 25° to 30° . In contrast, no landslide occurs at the riverheads in the lower areas with an inclination of only about 15° . The landslides on the southern slope of Mt. Minamidake where volcanic lavas are deposited occurred mostly in the area extending from the boundary of denuded land and grassland to the boundary of grassland and broadleaf tree zone. This is mainly due to the fact that the soil erosion is more serious on the denuded land and grassland than in the forested zone in heavy rains.

The debris caused by the landslide is swept downstream in the form of a mudflow. The deposits of volcanic lava fragments, the most typical of which are found on Nojiri River, contain masses of rock as well as great quantities of fine particles of materials such as volcanic ash, therefore, when impregnated with water they turn into a gruel-like state, greatly increasing their fluidity and become swiftly moving mudflow to rush downstream. Since the gruel-like material contains great quantities of masses of rock, it flows downstream wearing away the sides of the valley.

The mudflow begins to deposit where the slope of the valley bed becomes suddenly gentle, that is, a point where there is a topographical change.

As is presumable from the concentric distribution of contour lines, the area where there are such villages as Akaishi, Saihara and Nojiri were formed with deposits of sediment swept downstream in the ancient times by Nojiri River which repeatedly changed its course from side to side. This area is about one kilometer in width.

Table 4 Relationship Between Natural Environment and Landslides



5. QUANTITIES OF EARTH AND SAND PRODUCED BY LANDSLIDES

Since 1972, there have been increasingly intensifying volcanic activities, thus causing frequent landslides on Sakurajima. In order to grasp the realities of the landslides, a comparative study was made by use of aerial photographs taken in February 1971 when the volcanic action was relatively subdued to find the quantities of earth and sand discharged in the rivers on the yearly average during the period up to October 1974 (3 years and 7 months) as shown in Table 5.

Table 5 Yearly Average of Earth and Sand Discharges
in the Rivers on Sakurajima

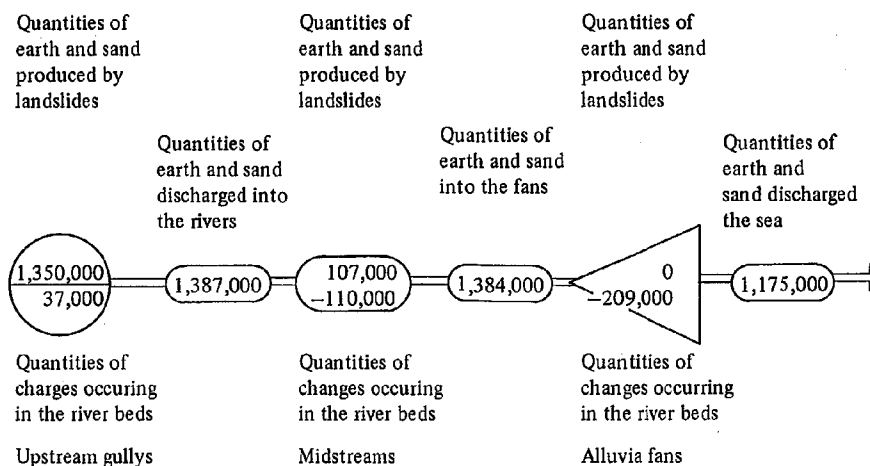
(Unit: $10^3 \text{ m}^3 / \text{km}^2 \text{ year}$)

Name of river	Drainage area	Oct. 1974 } Feb. 1971	Feb. 1971 } Mar. 1961
Nojiri River	2.99 km ²	106.2	35.0
Harumatsu River	2.09	21.9	
Mochiki River	1.61	40.3	
Daini-Furusato River	1.40	4.4	
Daiichi-Furusato River	0.85	13.5	
Arimura River	3.65	17.4	
Daiichi-Kurokami River	1.63	135.6	75.0
Daini-Kurokami River	5.25	53.5	34.0

As seen from this table, the figures are among the highest in this country. In order to investigate the effects of volcanic activities on landslides, a similar study was made on Nojiri River and Kurokami River, the representative rivers on Sakurajima, during a period of 10 years from March 1961 to February 1971 when there was a dull in volcanic action. As a result on the quantities of earth and sand produced by the landslides, it was found that during the last three years and seven months when there were the most violent volcanic activities the landslides progressed at a speed two to three times greater than during the period when the volcanic action was relatively quiet.

Table 6 a schematic representation of the earth and sand balance on Nojiri River in the last three years and seven months. It was also found that the larger portions of the earth and sand were transported as far as to the estuary.

Table 6 Earth and Sand Balance in Nojiri River



6. MUDFLOWS AND RAINFALL CHARACTERISTICS

Speaking about the conditions that induce mudflows on Sakurajima, it is presumed that they arise when a multiplicity of factors as rainfall, landslide and deposition of volcanic ash act in concert and a certain limit is exceeded by their combined forces.

In order to make observations of mudflows, monitoring facilities comprising video and cinecameras are set up mainly near the water channel in the downstream areas of the seven rivers (Harumatsu, Mochiki, Daiichi-Furusato, Daini-Furusato, Arimura and Kurokami) which have the highest incidence of mudflows.

(Fig. 2 and 3)

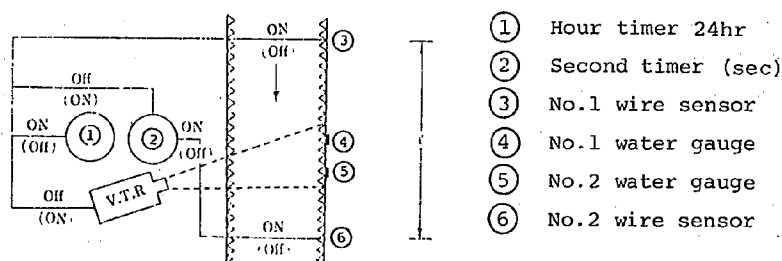


Fig. 2 Locations of Mudflow Monitoring Devices

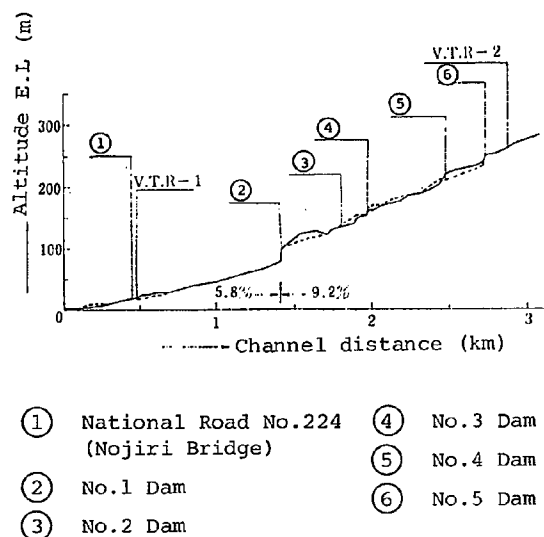


Fig. 3 Longitudinal Section of the Place where the Mudflow Monitoring Devices are Set Up

Since September 1974, the occurrence of twenty-seven mudflows have been confirmed by means of wire sensors, seismographs, VTRs or the reports from the residents who witnessed the mudflows. Table 7 shows the mudflows with a flow rate exceeding 10 m^3 per second.

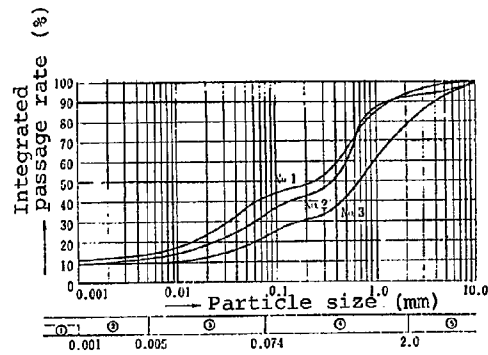
Normally mudflows do not occur if the effective rainfall intensity is less than 4 mm per second even when the effective rainfall is heavy. It is also believed that such mudflows do not arise when the effective rainfall is below 40 mm even if the effective rainfall intensity is high. In the case of Sakurajima, however, there have occurred such extraordinary phenomena that the incidence of mudflows is so high as 80% when the effective rainfall was below 40 mm and that several cases of mudflows have occurred even when the effective rainfall intensity was below 4 mm.

7. THE REALITIES OF MUDFLOWS

During a period from April 1975 up to the present, a total of twenty-one mudflows have been successfully recorded on video tapes. A set of four photographs shows the mudflow rushing through the water channel of Nojiri River on April 17, 1975. As is commonly called 'yama tsunami' (mountain tsunami), the earth and rock avalanche rushed in the form of bores down through the river, carrying in its front earth and rocks including so large masses weighing several tons. (Photos, 1-1 through 1-4)

Fig. 4 shows the results of analysis of the samples taken at intervals from the mudflow. The fluid density ranged from 1.8 to 1.9 gr/cm^3 and the ratio of water content to the dry weight of earth and rock was less than about 30%.

Fig. 5 shows the distribution of particle sizes in the deposits in the alluvial areas of the rivers. Suppose the



- | | |
|----------------------------------|-----------|
| 9 : 45, passage of the front, | ① Colloid |
| density, water content, | ② Clay |
| true specific gravity | ③ Silt |
| 10 : 00, water samples collected | ④ Sand |
| 10 : 20, " " " | ⑤ Pebble |
| 10 : 40, " " " | |

Fig. 4 Particle Sizes of Mudflow Samples
(Nojiri River, April 17, 1975)

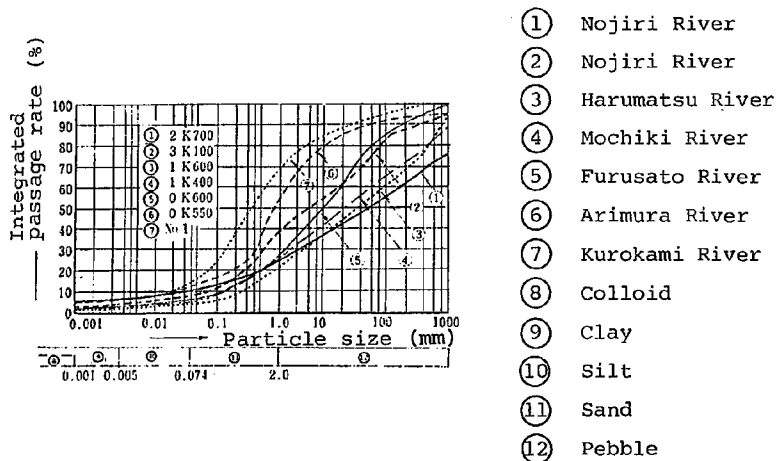


Fig. 5 Particle Sizes of Deposits on the River Bed

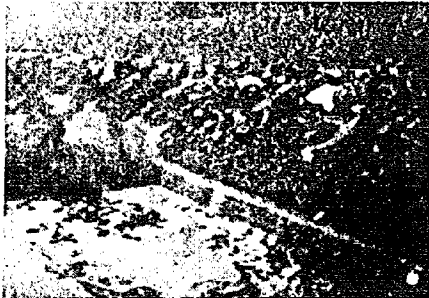
Table 7 Relationship Between Mudflow Occurrence and Rainfall

Name of river	Date of occurrence	Total rainfall (mm)	Effective rainfall (mm)	Rainfall per hour (mm)	Rainfall per 10 minutes (mm)	Effective rainfall intensity (mm/hr)	Flow (m ³ /sec)
	(1976)						
Nojiri River	Apr. 8	39.5	30.0	17.5	4.5	6.2	207.0
" "	" 17	84.5	59.5	16.5	12.0	6.0	476.0
" "	" 29	49.0	26.0	26.0	13.5	31.3	181.0
" "	June 4	65.5	42.0	23.0	9.0	9.7	287.0
" "	Aug. 8	45.0	22.5	21.5	8.5	19.4	29.0
" "	Oct. 3	15.0	8.0	8.0	4.5	16.0	21.7
" "	" 7	41.5	40.5	10.5	4.5	6.1	59.5
Daini-Furusato R.	Sept. 17	26.5	13.5	11.0	8.0	5.8	64.5
Kurokami R.	" 9	11.0	11.0	11.0	10.0	22.0	9.2
Arimura R.	" 17	26.5	13.5	11.0	8.0	5.8	329.0

earth and rock avalanches flow downstream with such particle size distribution unaltered, the total water content ratios would be extremely low.

Figs. 6-1 through 6-4 show the hydrographic records of four typical earth and rock avalanches of Nojiri River. Table 8 shows the hydraulic particulars of these mudflows.

In all cases of the most typical mudflows, the maximum water level was reached when their front passed by as seen from the photographs and the maximum velocity was also reached at this particular time. When the flow rate exceeded 200 m³, the front velocity becomes greater than 10 m per second. The duration of a mudflow of this scale was normally 60 to 90 minutes.



1-1 Just passing by No.1 water gauge



1-2 After passing No. 1 water gauge
(1 second later)



1-3 Immediately before passing by
No. 2 water gauge
(2.2 seconds later)



1-4 Just passing by No. 2 water gauge

Photo 1 The Realities of Earth and Rock Avalanche
(Nojiri River, April 17, 1975)

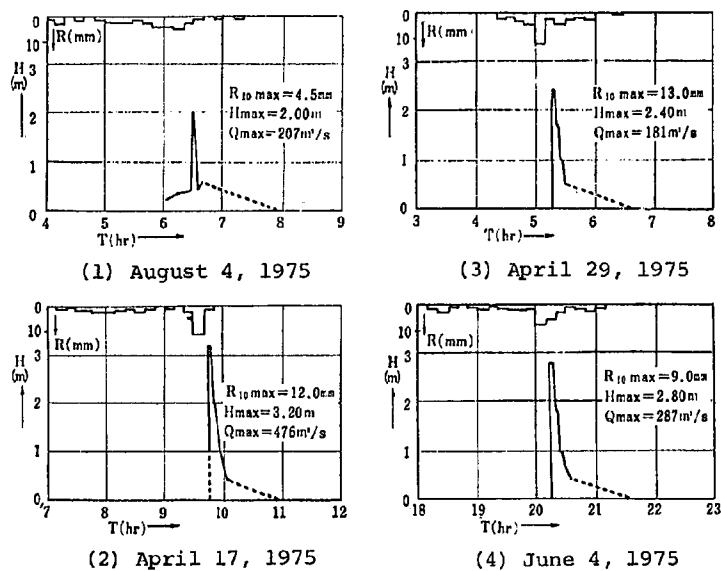


Fig. 6 Hydrographic Records of mudflow (Nojiri River)

Table 8 Hydraulic Particulars of Mudflow (Nojiri River)

Date of occurrence	Effective rainfall intensity (mm/hr)	Maximum water level (m)	Maximum velocity (m/s)	Maximum flow rate (m³/s)	Total quantities of earth and rock ($\times 10^3 \text{ m}^3$)
Apr. 8, 1975	6.2	2.0	11.5	207	94.0
" 17, "	6.0	3.2	13.6	476	194.1
" 29, "	31.3	2.4	7.8	181	64.2
June 4, "	9.7	2.8	10.0	287	121.2

8. CONCLUSION

The erosion control (Sabo) on Sakurajima is unique in that it is fight against the disasters due to volcanic activities and in a nutshell it comes down to what should be done to prevent the hazards of mudflows.

An increasing knowledge has been gained about the mudflows, small and large, which occur in heavy rain-falls on Sakurajima. However, there are still many questions to be solved and things to be done, such as the landslides which are accelerated by volcanic activities, the progress in denudation at the river sources due to the fall of volcanic ash, the quantitative analysis of the earth and sands which are produced in such quantities that can be said to be almost limitless, the clarification of the mechanism by which mudflows occur, and more advanced investigations on their realities. Now we are aware that we have just reached the initial stage of the difficult task.

**2—7. Lahars in Indonesia and Countermeasures
to Minimize its Hazards**

Mr. Ismangum SURYO

(Volcanology Advisor to
the Directorate of Rivers)

LAHARS IN INDONESIA AND COUNTER MEASURES TO MINIMIZE ITS HAZARDS

I. SURYO and Z. DAHLAN

SUMMARY

Since centuries lahars are known having been responsible for considerable loss of life and economic damage in Indonesia. There are two kinds of lahars in Indonesia; namely, lahars, caused by the ejecting of crater lake water and rain lahars that are caused by the action of rain.

Although both are highly destructive, the first mentioned type always claims a heavier toll. By means of draining away the water of the Kelut crater lake, the devastation caused by these eruption lahars could be reduced.

Rain lahars caused by torrential rains falling on newly deposited volcanic material on volcano slopes, up till now, still form a danger to low situating lands. Warning systems to inform the people of the coming danger and a timely evacuation have proved to save lives.

After the 1966 Kelut eruption, steps were taken by the Ministry of Public Works to control the volcanic debris flow by constructing engineering structures along the rivers. It is to be hoped that the Joint Study Programme between the Japanese and Indonesian Government to study the lahar flow, will result in the improvement of the counter measure methods against these dangerous lahar hazards.

1. INTRODUCTION

Considerable increase of loss of life by lahar hazard occurred during the last few decades in Indonesia, due to the rapid increase of inhabitants in lahar menaced areas. Consequently damage to villages, infrastructure and industrial estates are also increasing.

The eruption lahars, which is caused by the ejection of crater lake water, have been responsible for more loss of life than the rain lahars, which are the result of heavy rain falling on newly deposited loose volcanic material. Table 1 shows the casualties and loss of properties caused by lahars of Kelut, Agung and Merapi.

In this paper types of lahars, which have caused disasters in Indonesia and efforts to control lahar flow in order to minimize the possible loss of life and economic damage are discussed.

2. TERMINOLOGY

The Indonesian term "lahar" is used for a volcanic mud flow on the island of Java, in particular on the volcanoes Merapi and Kelut. This term was introduced for the first time in English literature by ESCHER and has now been generally accepted in volcanological and geological literature.

According to the Geological Nomenclature of the Royal Geological and Mining Society of the Netherlands,

"Lahar is a torrential waterflow mixed with volcanic mud and debris of all dimensions. The components do not settle according to size nor have they rounded edges."

3. TYPES OF LAHARS

We may distinguish two kinds of lahar in Indonesia viz.

1. Lahar caused by the ejection of crater lake water
2. Lahar caused by the action of rain (rain lahars).

3.1. Lahar caused by the ejection of crater lake water

These kind of lahars are caused either by eruption (eruption lahar) or by the collapse of a crater wall.

3.1.1. Eruption lahars

During an eruption the upper most disk of the crater water is thrown out. The temperature of this disk is not remarkable high. According to observes during the 1919 and 1966 Kelut eruptions, the first water flow was clear and not hot.

Meanwhile the temperature of the lower most disk has risen substantially and after mixing with the solid material from the eruption, the whole mass is thrown out and follows the rivers, having their source on the summit. The gases, that is still contained in the mass will escape, leaving behind the material in the ravines in a very dry and hot condition. The distance travelled by the emitted products depends on the specific gravity and water content.

3.1.2. Lahar caused by the collapse of a crater wall

This type of lahar is caused by the collapse of a crater wall, due to water pressure.

In the year 1875 such a phenomenon happened at the Kelut volcano. The crater lake wall probably became weak by the successive eruption lahars, so that on Jan. 29, 1875, the crater wall collapsed. Many hectares of arable land and gardens were destroyed by this calamity. But fortunately such type of lahar seldomly occur.

3.2. Lahar caused by the action of rain

3.2.1. Hot rain lahars

During an eruption a huge amount of volcanic material is deposited on the volcano slope and forms a mantle of loose material consisting of ash, sand lapilli and bombs.

The formation of lahar is mainly the result of the increase of the run-off coefficient caused by the reduced permeability of the soil, due to the ash cover on the higher part of the volcanic slope. Rainwater mixed with this unconsolidated material turns into a saturated mass with high density, which is flowing with increased velocity through the lahar material and after mingling with this still hot mass, form lahars in the middle and lower reaches. Such lahars are called rain lahars and because they are still hot, they are called also hot rain lahars.

3.2.2. Cold rain lahars

The preservation of heat in the lahar depends on the thickness of the deposit. It may last for months or years. After the lahar has cooled down, the lahars become cold and are called cold rain lahars.

4. ORIGIN OF LAHARS

It is well known that forest may reduce the flow of rainwater along the slopes, because of the capacity of trees to hold water and discharge it slowly afterwards.

At Merapi volcano the forest border is about 1500 m above sea level, while the area of the bushes is situated between the altitude of 1500 m and 2200 m. Higher than the 2200 m contour line the volcano is barren, and the falling water therefore will not meet any resistance.

These are the reasons why rain falling above the altitude of 1500 m may cause lahars and rain falling higher than the 2200 m contour line may cause dangerous lahars. However this applies only to rivers which have their source on the summit.

The forest border of the west side of the volcano is now lower situated, because of the influence of successive eruptions during the last decades. At this side lahar may originate, if rain fall at the altitude of 1200 m.

Ash falling on a slope of a volcano may become a crust and forms a quite impermeable layer. It results in the increase of the run-off. This phenomenon is of influence at the barren area and at the area of the bushes, while at the forest area, most of the ash will fall on the leaves and branches of the trees.

Above the forest area the ash forms a thick layer immediately after the eruption. In this barren area, consisting of sand layers, breccia and lava streams, the ash will be quickly washed out. Only a small amount is left and forms with the unconsolidated rocks a not well cemented breccia, which will be slowly eroded.

The rainwater will easily take the ash from the deposit falling down on the "gliding plane", which is chiefly consisting of loose sand material.

In the breccia area new gullies are formed. Through these new erosion gullies the rain water will flow easier and is concentrated to certain valleys, than in normal condition.

5. BEHAVIOUR OF LAHARS

5.1. Eruption lahar

During the eruption the crater water is ejected and rushes down the slope in several directions. Summit erosion and erosion in the middle reaches takes place. Sedimentation of the plain starts as soon as the ravines become undeepest. The material is chiefly consisting of old volcanic material from the summit and boulders from river beds and river walls.

After that, sedimentation of ejected volcanic material starts on the upper reaches and on the flat parts of the summit. On the middle reaches a gradual transition between erosion and sedimentation takes place. At last sedimentation of lahar in the rivers and on the summit part occurred, while sand and ash are deposited on the whole volcanic body.

5.2. Rain lahar

The erosion of the upper slopes is small, immediately after eruption, because the new material must be eroded first. The lahar, which flows down during the first rainy season, consist chiefly of water, ash and pumice. This lahar has still a high temperature, because of the still hot lahar material. Big tree trunks and boulders will be taken during its downwards movement.

Halfway to the plain erosionwater from the middle reaches add to the lahar mass, which becomes gradually more sandy.

Erosion and sedimentation in the middle and upper reaches takes place, but the erosion is stronger. Sedimentation occurs particularly on the plain.

After the ash has been washed out, the upper reaches are affected and the lahars become more and more sandy.

Gradually the vegetation becomes more dense and surface water decreases in quantity. The erosion is restricted to steep valley walls and river beds. In the middle reaches, the erosion decreases and the sedimentation increases. The river bed becomes higher and may at last reach its old level.

6. PROPERTIES OF LAHAR

During normal condition only a small amount of rain water is running along the slopes of a strato volcano, while the biggest amount of water penetrates the porous volcanic soil and comes out as a spring at the foot. After an eruption, however, the soil of the volcano slope is covered with an ash layer, which makes the soil almost impermeable. This reduced permeability results in an increase of the run-off coefficient. The loose volcanic material mixed with the rain water increases the volume of the mass, which runs down the slope. The velocity increases because of the increase of the volume of the mass, according to the formula, which has the same form as the Chezy formula:

$$v = k \sqrt{\frac{F}{u}} \sqrt{i}$$

v = velocity of the stream

k = resistance factor

F = cross section of the stream

u = perimeter of the wet part of the valley profile

i = gradient

After the mass has been mixed with old volcanic material picked up during its downwards movement, it flows into the lahar material and mingles with it.

The friction of the lahar mass on the valley walls and on the bottom is very strong. That is the reason why the highest velocity is to be found in the middle of the stream. As long as the mass is flowing between the high valley walls, the velocity is fast enough to overcome the friction, but if the bed becomes wider the sedimentation starts and erosion gullies occur. If the lahar flows over its banks and spread over the plain, the friction becomes too big and the material has not so much velocity to flow further. Sedimentation occurs over the whole overflowed area.

In an usual waterstream the heavy material moved along the river bed, while the light material is flowing on the upper parts. In a lahar stream, however, the heavy material may move on the upper as well as in the lower part of the stream.

The pushing movement of the lahar flow is characteristic. This phenomenon is caused by the throwing up of small dams in its course, that at any moment may again be destroyed. Stagnation occurred, which is followed by an increased speed of the lahar mass.

The formation of lahar terraces is also characteristic in lahar deposits.

7. MINIMIZING THE LAHAR HAZARDS

7.1. Hazard map and lahar warning system

The first step to minimize possible victims caused by lahars is to prepare hazard maps of dangerous volcanoes where areas with different hazards are distinguished. The next step is to establish lahar post along the dangerous rivers for the purpose of lahar warning and finally to reduce the possible economic damage, it is necessary to build structures along the rivers, which are considered to be dangerous.

About the hazard map an explanation is already given in the paper, "Nuées ardentes at Merapi volcano and precautionary measures against these volcanic phenomena".

Table 2 shows the areal extent and the population of the second danger zone for the volcanoes Merapi, Kelut and Agung.

Table 2. Areal extent and population of the second danger zone of Merapi, Kelut and Agung

Volcano	Areal extent (km ²)	Population (x 1000)
Merapi	99,6	93,2
Kelut	252,4	145,3
Agung	25,6	29,2

In the rainy season during and after the activity of the volcano, the following measures are taken.

If a lahar flow is expected along certain rivers the Merapi Project in cooperation with the Local Irrigation Office should observe these rivers from newly erected temporary observation posts. The above mentioned temporary lahar posts have to use "gongs" to warn the people living in the second danger zone.

1. Signal "Beware of lahar"

If rain is falling with the intensity of about 70 mm within 35 minutes or if the seismograph is recording the beginning of a lahar formation, the volcanological observations should pass the warning "Beware of lahar" to the nearest telephone office. The telephone office at once passes this information to the officials concerned.

2. Signal "Run"

This danger signal (continuous striking on the gong) is given by the lahar posts along the rivers. As soon as a telephone officer learns this signal, the warning is at once passed to the District Head, who in turn passes this warning to the officials concerned. When the signal "Run" is heard, the community along the rivers concerned should at once evacuate to higher places.

In 1956 two electrical raingauges had been installed at an altitude of 1500 m above sea level. These raingauges were connected with wires to Krakatau observatory for the warning of Apu river and to Babadan for the warning of Trising and Senowo river. If rain fell with the intensity of 70 mm within 35 minutes the observatory concerned gave the danger alarm.

But as the cables were later on cut by the people, these system of detection could not be maintained. Now

the Volcanological Survey used seismographs instead. For the detecting of advancing lahars at Merapi is now used seismographs of low sensitivity. After the seismographs indicate the first sign of the development of lahar, at once the gong alarm is stricken.

7.2.1. Measures against eruption lahars

1. drainage of the crater lake

It was after the 1919 Kelut eruption which caused the death of 5110 persons, when concrete steps were taken by the Government to drain the crater lake and to keep the volume of the lake water at a minimum, HETTINGA TROMP, a Dutch engineer had constructed a series of tunnels through the crater rim to drain away the water of the crater lake, so that eruption lahars in the future would do less damage.

The first tunnel was driven just above the lake surface. The lake water was then siphoned from the lake through the tunnel until the lake level was lowered. Again another tunnel was driven just above the new lake surface. This process was repeated until 7 tunnels. The crater lake water was then reduced to 1,8 million cu. meters.

The 1951 eruption nearly did not produce eruption lahars, as most of the water had been evaporated. The eruption lahars had reached the maximum distance of 8 km. No people was killed by the lahars. The reported 6 victims was actually caused by the Nuées ardentes. The tunnel project, therefore was a success. This eruption, however, resulted in a lowering of the crater bottom and the destruction of the intakes of the tunnel system. The crater bottom appeared to be 70 m lower than before the eruption.

After the lowest tunnel and the main shaft were rehabilitated by Van YZENDROORN, still 23 million cu. m water remained in the crater.

The 1966 eruption again caused lahars of the eruption type and more than 200 people were killed by this phenomenon. The crater bottom rose 20 m. A new tunnel 20 m below the former lowest tunnel was completed by the late ADELI AYUB in 1967, and the lake is now drained to a volume of 4.5 million cu. meters. Loose material in the form of ash and sand deposited on the inner crater wall was afterwards washed out by rainwater and redeposited in the crater. This resulted in the heightening of the crater bottom. In the beginning of 1976 the volume of the crater water became 3 million cu. m. It is estimated that the expected eruption lahars during the next eruption will reach the maximum distance of less than 12 km in the Badak river, which means that overflowing here will do no harm, as the lahar material will be then intercepted by the Salam lahar pocket.

As is known already the level of the crater bottom changes after each eruption and it is therefore necessary to calculate the new volume for estimating the possible danger caused by the lahars of the next eruption. From experience we know that 1.8 million cu. m of crater water did not cause eruption lahars, but up till now the maximum volume of water, which may remain in the crater, to prevent the formation of eruption lahars, is not yet estimated.

7.2.2. Measures against rain lahars

1. check dams

Check dams are well known in engineering practices in Indonesia and have been used in river training and in irrigation channels. But as a counter measure against lahar hazards, checkdams were first used in Nambaan river after the 1966 Kelut eruption. These series of checkdams were of the gabion type.

Some years later, the late Mr. T. Yokota, Colombo Plan expert attached to the Directorate of Rivers introduced in Indonesia the full concrete type. The first Sabo dam was constructed at Putih river, upstream of the already finished lahar pocket of the same name. It was Mr. Yokota too, who had introduced the Sabo dam design development to his Indonesian colleagues.

Regarding its material, the stone masonry (also called Indonesian concrete) is more used in Indonesia due to its low cost as compared with concrete. Later on a combined type check dam, consisting of an inner part made of masonry and a concrete outer part, becomes more popular than both above mentioned types.

Concerning the design of a checkdam in engineering practices in Indonesia, it is worth to note that a few Indonesian engineers are of the opinion that the checkdam's foundation in a river bed with lahar material can be made thinner than the thickness derived from the formulas used in Sabo dam engineering. This theoretical problem of design standardization is still unsolved.

Field observation on the effect of lahar flows on a Sabo dam during its operation life time can be hoped to give the solution in the future. But unfortunately, in Indonesia, due to lack of funds, we are not able yet to construct series of checkdams along a river as many as are needed. Observations on this matter, therefore, will give no satisfactory results, as long as the needed series of checkdams along a river are not built.

2. lahar pockets

Lahar pockets are large areas defined by dikes, with a view to intercepting lahar material. This method of localizing volcanic material brought by lahars, becomes more popular not only on Kelut area but also on other volcanoes as Agung and Merapi.

It is considered as an effective counter measure against lahar hazard and against possible invasion of material into irrigation canals as well as into principle rivers.

It is worth to note that this new method of localizing material was first applied at Jatilengger area on the Kelut volcano slope. At that time (1966) Jatilengger area was devastated by the eruption lahar. Later on more devastation occurred caused by the rain lahars, which spread to all direction. To limit its spreading and to prevent more damage, the already destroyed area was immediately defined by dikes forming a large pocket. As the gradient is here 1,4 per cent the material is easily deposited, while clean water is giving the possibility to flow out of the pocket via an overflow. In the beginning the dikes were often destroyed by side erosions, but after the flow had been regulated by constructing groins and after the weak parts of the dike were reinforced, the Jatilengger lahar pocket was functioning well. Another pocket constructed on the west part of the volcano, however, did not come up to expectation. Here we have been forced to divert the lahar flow at a high altitude

on account of the densely populated area downstreams. Because of the steep slope, which is 4,6 per cent, the lahar had still a high velocity. Checkdams were built lateron to reduce the velocity of the lahars and besides that three other concave dikes were successively built below the first one. These two lahar pockets were actually built as a temporary measure to minimize further destruction by the first lahar flows.

After the volume of the material in the head waters of the rivers have been calculated, new lahar pockets were built afterwards.

Except the two mentioned lahar pockets, for the Kelut volcano 5 more pockets were constructed namely Salam, Putih, Semut, Konto, and Srinjing.

Table 3 shows the data of the lahar pockets on Kelut volcano slope.

Table 3. Lahar pockets on Kelut volcano slope

No.	Name of pocket	River	Gradient (%)	Length of dike (km)	Storage capacity (million cu. m.)	Material already deposited (million cu. m.)
1.	Jatilengger	Badak Jatipelen	1.4	10.8	6.5	4
2.	Pulo	Ngobo	4.6	3.9	4	2.6
3.	Salam	Badak	2.8	12	8	6
4.	Putih	Putih	2.1	7.6	8	6
5.	Semut	Semut	2.7	6	5.6	4
6.	Konto	Konto	1.0	2.5	2.5	0.26
7.	Srinjing	Puncu	2.0	1.4	0.6	0.2

Conclusion

Lahars form a frequent hazard in volcanic environments particularly in densely populated areas. A good warning system to inform people in time of the advancing lahar may save life. By draining crater lakes and constructing engineering structures along rivers, where lahars are expected to flow, economic damage can be reduced.

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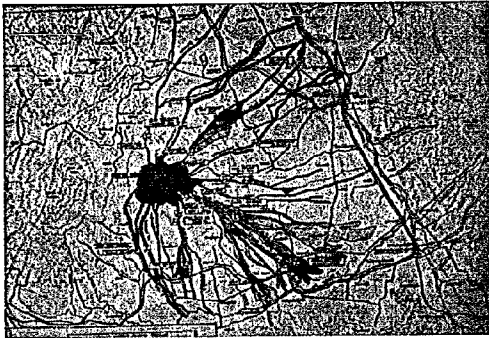
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Table 1. Casualties and loss of properties caused by lahars at G. Kelut, G. Agung and G. Merapi

Volcano	Year	Date of eruption	People				Villages				Houses				Heads of cattle		Arable land (Ha)				Bridges		Dams		Remarks	
			Killed		Injured		Destroyed		Damage		Destroyed		Damage		Killed		Destroyed		Damagae		Damage		Damage			
			er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar	er. lahar	rain lahar		
Kelut	1826	Oct., 13	*	*			65																			
	1848	May, 16	21	*			11																			
	1864	Jan., 3-4	many	*			*				hundreds				much											
	1875	Jan., 29	*	*			30																		Great damage	
	1901	May, 22-23	many	*																					Great damage	
	1919	May, 19	5110	*			104				8995					1571		13,500				44		*		
	1951	Aug., 31		*																	7000					
	1966	Apr., 26	282	3	73		57			81	723		1897	273	1196	76	2266,58	7394,58	113		1807	19	2	86		
Agung	1963	Mar., 16 May, 17		165		36		16		5		3519				2553		1832				20		*	Caused by lahars in 1963 and 1964	
Merapi	1961	May, 9		1				1					4													Caused by lahars after eruption of Jan., 1969
	1969	Jan., 8		2						22		641		32						524.5						Caused by lahars after the eruption of Dec., 1973
	1974									3		27		32						16						Caused by lahars after the eruption of Dec., 1973
	1975													20						10						Caused by lahars after the eruption of Dec., 1973

* no record

Mr. Suryo's photographs



Distribution of Lahar flow of KELUT
(1916, 1951, 1966)



Deposit of Eruption Lahar
(KELUT Volcano 1966)



Eruption Lahar Deposit of 1966
KELUT ERUPTION
(Photo. Feb., 1972)



Hot Rain Lahar
(KELUT 1966)



Devastation caused by Hot Rain Lahar
(KARANGASEM, AGUNG Volcano)



Hot Rain Lahar
(KELUT Volcano 1966)



Cold Rain Lahar
(SEMERU Volcano Dec., 1977)



Cold Rain Lahar
(SEMERU Volcano Dec., 1977)



Cold Rain Lahar
(SEMERU Volcano Dec., 1977)



Lahar devastation in Bali
(AGUNG ERUPTION 1963)



Destruction by Rain Lahar
(AGUNG Volcano 1964)



The first Sabo Dam built in Indonesia
(Watugede, K. Putih)

2—8. Debris Flow Disaster and its Countermeasure in Japan

- i) Sabo works in JAPAN**
- ii) Information on the debris flow disaster in
Mt. IWAKI and its improvement plan**

Mr. Tadahiro MATSUSHITA

(Erosion Control Division, M.C.)

i) SABO WORKS IN JAPAN

Tadahiro MATSUSHITA

Assistant Director
Sabo Division, Sabo Department
River Bureau, Ministry of Construction

Foreword

"Those who control the rivers rule the country" is still the well-known saying in Japan from olden times. It substantially reflects that the control of rivers has been the mainstay of policy of the Japanese administrations which have attached special importance to the works of river control.

Due to the influence of natural conditions, such as topography, geology, heavy rainfall, etc., Japan has been suffering from disasters caused by floods, mudflows and landslides repeatedly in the past.

To cope with such unfavorable natural conditions, Japanese in olden times had already developed methods of river control peculiar to Japan. In the modern age, new technics in this field have been introduced from foreign countries as well as developed by the Japanese themselves.

In this writing, an introduction of Sabo works in Japan is attempted, which are the base of river control works and the unique development of river control works in Japan for the prevention of disasters caused by mudflows and landslides. The intention of the author is also to exchange information of Sabo works with foreign nations, since the word "Sabo" has already been known internationally.

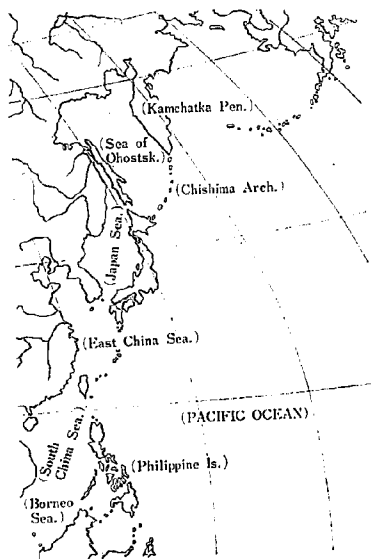


Fig. 1 Location of Japan.

Nature and Environment of Japan

Location

The land of Japan is consisted of a chain of islands spread in an arch form and surrounded by many islets, which lies to the east of Continent of Asia and the west of Pacific Ocean, i.e., from 123° to 154° east longitude and from 20° to 45° north latitude. The territorial length from north to south measures approximately 2,500 km, the maximum width is about 300 km and the area 377,000 km². The population of the nation is approximately 113 million.

The four main islands are Hokkaido, Honshu, Shikoku and Kyushu, which are surrounded by many islets. The whole country, thus, is blessed with a beautiful natural environment. The stretching of the land from the northern subarctic zone to the southern subtropic

zone provides a distinct variation of the four seasons in a year.

Topography, Geology and Tectonics

As Japan is situated in the Circumpacific Volcanic Zone and the seismic zone, the crustal movement within her territory including volcanic activities and earthquakes is very active.

As there are many volcanoes in Japan, the tallest one being Mt. Fuji, and as her crust is enormously moved by the fault fractured zones called Fossa Magna and Median Tectonic Lines, the geological tectonics of her land is very fragile.

Geologically, almost the whole of her mountainous areas is composed of the fragile Tertiary and the new volcanic rocks, while the remaining part is composed of plutonic rocks such as granite, which are likely to be weathered.

As 70% of the terrain is occupied by mountainous areas, and as a chain of high mountains runs along the center line of the small and slender archipelago, short and steep rivers flow from these mountains and form alluvial cones at their downstream reaches. Thus, the topography of Japan is very rugged.

As most of the population inhabits these alluvial cones where various disasters are bound to occur, they are destined to suffer accordingly.

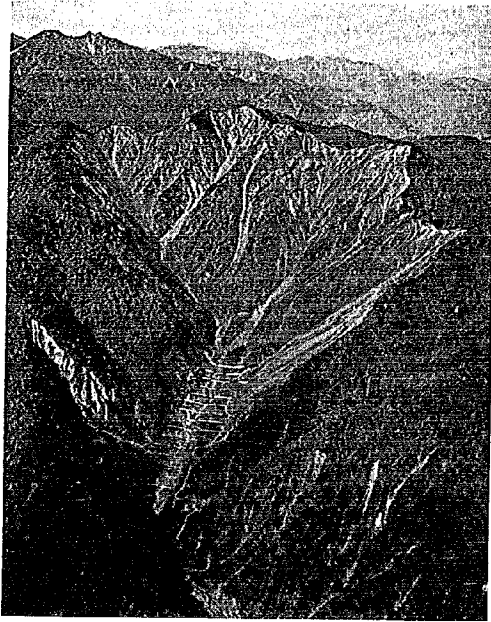


Photo 1 Devastation of Mountain Area (Abe River).

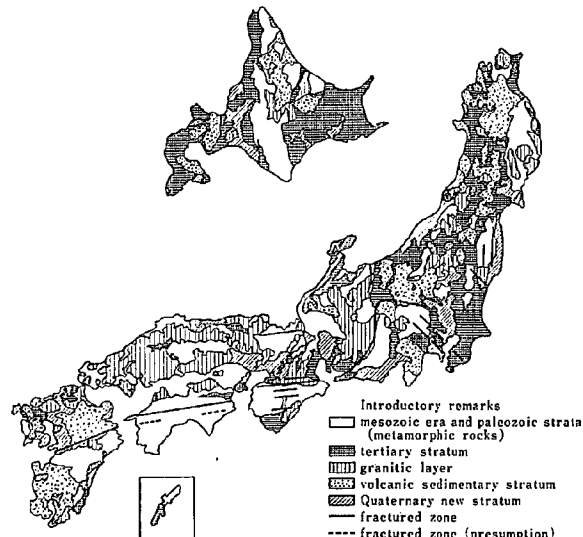


Fig. 2 Geological Map of Japan.

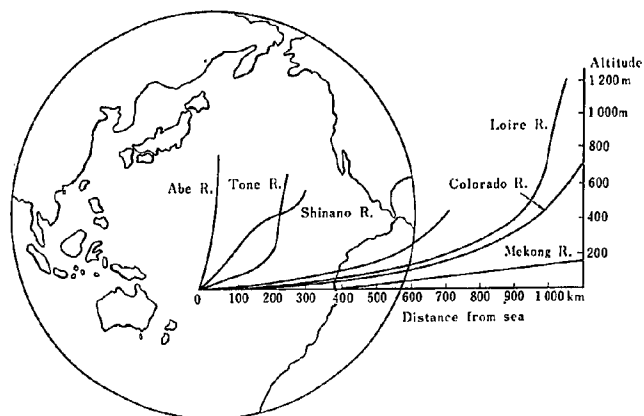


Fig. 3 Vertical Slopes of Principal Rivers in the World.

Meteorology

Japan is a region of heavy rainfall because the continental air current and the oceanic air current merge here. Moreover, the locally concentrated torrential rainfall usually pours down due to the frequent attacks of typhoons and the complicated topography of the country.

Meteorologically, Japan is divided into two characteristic sides by the chain of mountains at the center line of the archipelago, namely the Pacific Ocean side and the Sea of Japan side.

On the Sea of Japan side, there are heavy snowfalls in winter owing to the influence of seasonal wind from Siberia. The thawing from March to May is easy to cause disasters such as mudflows and landslides. On the Pacific Ocean side, there are less snowfalls but it is frequently attacked by the locally concentrated torrential rainfalls induced by the Baiu front in June to July as well as by torrential rain-

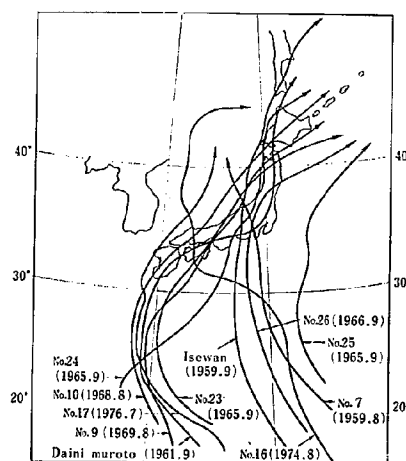


Fig. 4 Paths of Recent Typhoons.

falls brought by typhoons from August to October.

The annual rainfall of Japan, therefore, exceeds 2,400 mm in many regions. Especially at a part of Kii Peninsula, it reaches as much as 4,000 mm.

Precipitation is the essential source to power generation, water supply and irrigation, etc. However, the concentrated rainfall in a short period is the cause of disasters such as mudflow and landslide.

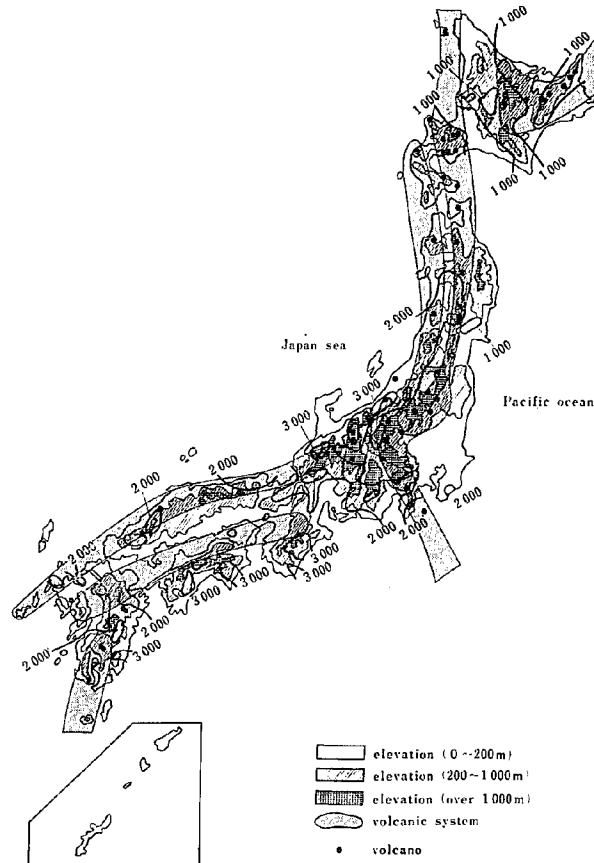


Fig. 5 Distribution of Annual Rainfall.

Population and Land Utilization

As above mentioned, Japan has a population of approximately 113 million dwelling on an area approximately 377,000 km² big. Thus, the population density is 300 persons/km². (Population estimation as of Oct. 1, 1976).

The actual state of land utilization in Japan shows 1,140,000 ha of residential land, 3,110,000 ha of paddy field, 2,650,000 ha of dry field, 90,000 ha of lake and marsh, 15,500,000 ha of forest, 270,000 ha of pasture, 2,000,000 ha of wasteland and the remaining of land of other kinds.

By the topographical characteristics of Japan, about 10% of her land, i.e. 36,500 km², belongs to the inundation areas of rivers. In such areas, about 50% of her population lives. The properties in these areas worth approximately as much as 270 billion Yen which is about 68% of her national property of 400 billion Yen (estimation of 1975).

[Note: The billion is English numeration]

Actual State of Disasters due to Mudflow and Landslide

In this paragraph, a description is made on the actual state of disasters caused by mudflows and landslides resulted from devastation of mountainous areas and mountain torrents.

As mentioned, more than 100 million Japanese live in a narrow land where 70% is the rugged area. Therefore, houses, railroads, roads, hospitals and public utilities concentrate in the remaining small plains which are composed mostly of alluvial cones.

Thus, from the topographical and geological characteristics, the whole land of Japan is very weak in resistance against disasters, and every year the alluvial cones and rivers suffer miserable damages caused by disasters of mudflows and landslides or others.

In coping with the situation, Sabo works are being carried out in two major categories, namely, for the conservation of devastated water source areas and as the preventive measures of local mudflow disasters. And the importance of Sabo works is increasing year after year.

The disasters due to the flow of sediments are classified into two kinds. One is the disaster caused by the flowing sediment such as mudflow. The other is the temporary or continuous deposition of sediment in river channels or dams, which causes inundation by flood and reduction in dam function.

Table 1 Serious Disasters Caused by Mudflows.

Date	Prefecture	Region	Cause	Damage Condition	
				Persons Dead or Missing	Houses Damaged
July 1945	Hiroshima	Kure City Vicinity	Nakurazaki Typhoon	1154	1954
Sept. 1947	Gumma	Akagi Vicinity	Typhoon	271	1538
July 1951	Kyoto	Kameoka Vicinity	Typhoon Front	114	15141
June 1953	Kumamoto	Mt. Aso Vicinity	Baiu Front	102	Unknown
July 1953	Wakayama	Arita Vicinity	Baiu Front	460	4772
Aug. 1953	Kyoto	Minamiyamashiro-Ueno Vicinity	Typhoon Front	336	5122
Sept. 1958	Shizuoka	Kanogawa Vicinity	Typhoon No.22	1094	19754
Aug. 1959	Yamanashi	Kamanashigawa Vicinity	Typhoon No.7	43	277
June 1961	Nagano	Inatani Vicinity	Concentrated Rainfall	130	3018
Sept. 1966	Yamanashi	Saiko Vicinity	Typhoon No.26	32	81
July 1967	Hyogo	Omote Rokko	Concentrated Rainfall	92	746
July 1967	Hiroshima	Kure City Vicinity	" "	88	289
Aug. 1967	Niigata	Kurogawamura	" "	31	1102
July 1972	Kumamoto	Amakusa Vicinity	" "	115	750
July 1974	Kagawa	Shodoshima	Typhoon No.8	29	1139
Aug. 1975	Aomori	Mt. Iwaki	Concentrated Rainfall	22	28
Aug. 1975	Kochi	Niyodogawa Vicinity	Typhoon No.5	68	523
Sept. 1976	Kagawa	Shodoshima	Typhoon No.17	119	2001

Devastation of Mountainous Areas

The water source areas in mountains of Japan have been obviously devastated from the viewpoint of topographical and geological characteristics. Especially in the area of volcanic calderas or tectonic fractured zones, large-scaled landslides, barren hills or slide debris deposits appear and occur. These devastated areas are classified as the heavily devastated area and the generally devastated area according to the degrees of devastation. The heavily devastated area occupies a total space of 3,700 km² which covers 14 areas of the tectonic fractured zone in Central and South Japan Alps and the volcanic caldera in North Japan Alps. The generally devastated area occupies a space of 50,000 km² which covers 26 areas in the central mountains and mountains in Shikoku.

The areas of large-scaled landslides which cast the serious influence over the residential areas in the lower reaches occupy a total space of 350 km² throughout the country.

Table 2 Generally Devastated Areas.

Name of Area	Area	Name of Principal River
1 Ishikari sanchi	1,988 km ²	Ishikari, Tokachi, Wakibetsu, Joro
2 Hidakasanchi	1,212	Tokachi, Shionai, Rekiyone, etc.
3 Shiragamisanchi	712	Iwaki, Akaiishi, Yoneshiro
4 Chokai san	160	Neyoshi, Hiyaga, Mogami
5 Kitagami kogen	1,264	Ito, Komoto, Kitagami
6 Oousanmyaku	2,404	Omoto, Kitagami, Mogami, etc.
7 Bandai, Asahi	2,475	Mogami, Arakawa, Aburama, etc.
8 Tadami, Nikko, Joshinetsu	6,026	Agano, Tone, Shinano, etc.
9 Tama, Chichibu, Tama	1,568	Tone, Arakawa, Fuji, etc.
10 Tanazawa	304	Sagami, Sakawa, etc.
11 Mt. Fuji	182	Utsui, Shiba
12 Izu	324	Kano
13 Chu-shinkogen	432	Shinano, Tenryu, Fuji
14 Minami Alps	3,465	Fuji, Abe, Utsi, Tenryu
15 Chubusangaku	10,049	Shinano, Kiso, Jozoji, etc.
16 Suzuka-sanmyaku	272	Suzuka, Asakura, Yodo, etc.
17 Hira, Tanakamiyama	220	Yodo
18 Kii-sanmyaku	3,637	Kinokasa, Kumano, Arita, etc.
19 Higashi-Chugoku-sanmyaku	1,016	Yats, Tazawa, Sendai, etc.
20 Daisen	392	Tenjin, Ito, etc.
21 Hiba, Dougo	445	Hono, Hii, Goukawa, Takahara
22 Nishi-Chugoku-sanchi	355	Takatsu, Monzen
23 Shikoku-sanchi	5,221	Yoshino, Nigodo, Shigeno, etc.
24 Aso, Kuju	2,035	Chikugo, Ono, Shirakawa, etc.
25 Kyushu-sanchi	2,620	Kuma, Hitotsuse, Ogodo, etc.
26 Mt. Kirishima	236	Ogodo, Sendai, Amori
Total 26 Areas	50,000	

Table 3 Heavily Devastated Areas.

Name of Area	Area	Name of Principal River
① Gassan	309 km ²	Mogami
② Tanigawa-dake	156	Tone, Shinano, (Ono)
③ Nantai, Akagi, Ashio	244	Tone (Kina, Waterase, Tone)
④ Asama, Shirane	184	Tone, Shinano (Chikuma)
⑤ Hakuba, Kita-Alps	551	Shinano, Jozeanji, Kurobe, Hime, Jintau, Hayatsuki
⑥ Hakusan	199	Tedori
⑦ Chuo, Minami-Alps	1,071	Fuji, Tenryu, Ooi, Abe, Kiso
⑧ Mt. Fuji	50	Utsui, Shiba, etc.
⑨ Arita	167	Arita, Shingo
⑩ Daisen	76	Hime, Tenjin, Amida, etc.
⑪ Yoshino	245	Yoshino, Naka, Monobe
⑫ Ishiuchi	226	Nigodo, Yoshino
⑬ Aso	64	Shirakawa
⑭ Kirishima	32	Ogodo
Total 14 Areas	3,700	

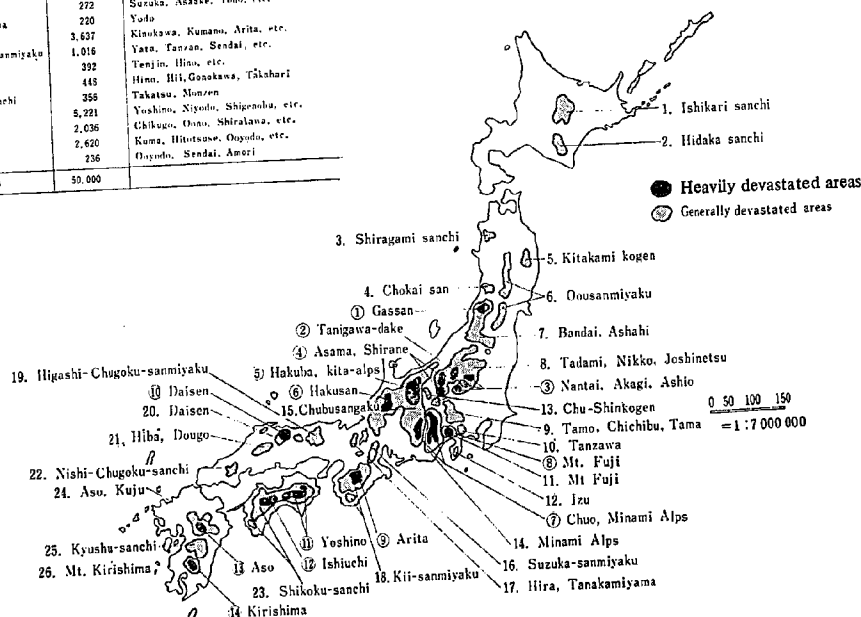


Fig. 6 Conservation of Water Source Areas in Japan—Distribution of Heavily Devastated Areas and Generally Devastated Areas.

Dangerous Mountain Torrent Causing Mudflow Disaster

Recently, disastrous mudflows successively occurred in Japan, such as the one in Amakusa in Kumamoto Prefecture in 1972, the one in Shodoshima in Kagawa Prefecture in 1974, another one in Niyodo River in Kochi Prefecture in 1975 and a further one in Shodoshima in 1976. Many lives were lost due to these disasters, and many properties were damaged. Mudflows suddenly resulted from torrential rainfalls, thus, have a tremendous destructive force causing heavy loss in human lives and properties in an instant. In the whole Japan, there are as many as 62,000 mountain torrents causing the danger of mudflow, and there are 5,600 mountain torrents having the danger of landslide. Totally, there are about 67,600 dangerous mountain torrents throughout the whole nation, and about 64,000 dangerous places of steep slope failure (investigated as of 1977).

Table 4 Number of Torrents in Which Prevention Measures of Disaster Caused by Mudflows or Landslides are Necessary.

Improvement Index	Unit	Long-Term Target
Torrents for Improvement	Number of Torrents and Area	132 172
Mudflow Torrents	"	62 272
Landslide Areas	Number of Area	5 616
Steep Slope Failure Areas	"	64 284

Outline of Sabo Works

Purposes of Sabo Works

The purposes of Sabo works are to conserve water source mountainous areas in face of devastation, protect human lives and properties from disasters caused by mudflows and landslides, consolidate the foundation of communities and contribute to the welfare and development of regions.

Kinds of Sabo Work

Sabo works are generally classified into three kinds. One is for the prevention of disasters caused by mudflow through conservation of water source mountainous areas, another is for the prevention of landslides and the third is for the prevention of disasters due to steep slope failures.

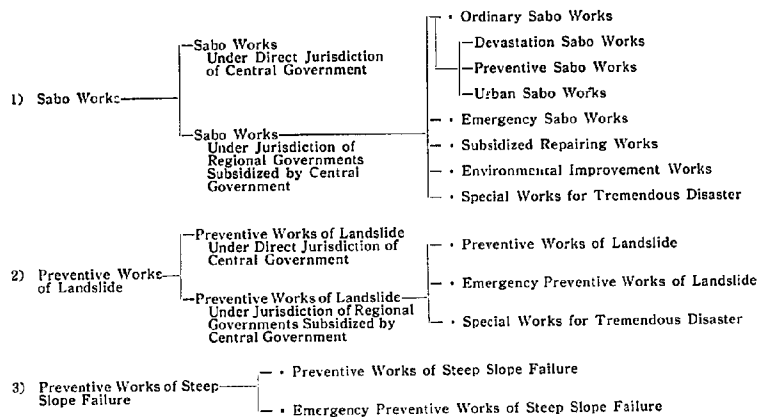
By jurisdiction of execution, Sabo works and landslide prevention works are classified into two categories. One is under the direct jurisdiction of the central government and the other under the jurisdiction of the regional governments with the subsidy of the central government.

The works executed directly by the central government are:

- The devastation is too extensive to be handled by one regional government
- The devastation is too large in scale and works are difficult, and
- The cost of works is very huge.

The works for prevention of disasters due to steep slope failure are undertaken by the regional governments and subsidized by the central government.

The above mentioned works and their executions in relation to jurisdictions are illustrated in charts as follows:



Laws for Prevention of Disaster Caused by Mudflow and Landslide

There are enforced three laws for the prevention of disasters caused by mudflows and landslides, namely "Sabo Law", "Law Concerning Prevention of Landslide" and "Law Concerning Prevention of Disaster due to Steep Slope Failure". The descriptions of these laws are as follows.

Sabo Law

The Sabo Law which came into effect in 1897 is one of the earliest laws governing river control works. At present, Sabo works are executed in accordance with this law.

This law prescribes the fundamental matters in the execution of Sabo works, such as the designation of the land necessary for Sabo works for the prevention of disasters caused by mudflows and devastation, and the prohibition of certain activities in a certain land for the purpose of land conservation, by Minister of Construction, the determination of Sabo works carried out under the direct jurisdiction of the central government, and the subsidy from the central government for Sabo works executed under the jurisdiction of the regional government, etc.

Law Concerning Prevention of Landslide

This law which came into effect in 1958 prescribes the basic matters with respect to landslide preventive works, such as the designation of the necessary areas for works, the concept on allocation of the necessary budget for the preventive works, problems of maintenance, etc.

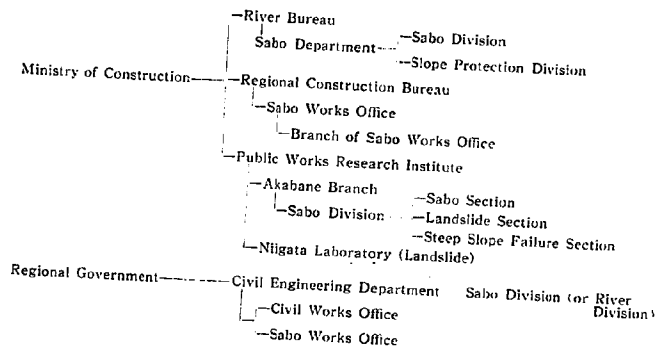
Law Concerning Prevention of Disaster due to Steep Slope Failure

This law which came into effect in 1969 prescribes the basic matters, such as the designation of areas which are endangered by the steep

slope failure, conservation of the necessary land, orders for improvement, work cost allocation, establishment of warning system and evacuation, sharing of cost by beneficiaries, funds for removal of houses, etc.

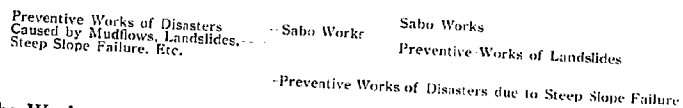
Execution System of Sabo Works

The execution of Sabo works in Japan is undertaken by the Sabo Department of the River Bureau, Ministry of Construction, and the execution system is as follows:



Contents of Sabo Works as Mainstay for National Land Conservation

Described in below are Sabo works, preventive works of landslides and preventive works of disasters due to steep slope failure:



Sabo Works

Sabo works of this kind are classified into three categories as follows:
One is against the disaster of flood inundation caused by the reduction of river channel capacity and the uprise of river bed caused by the large quantity of sediment flowing out from the mountainous area. Another is against disaster which causes the loss of human lives and properties due to the sediment itself flowing out suddenly from the mountainous area like the mudflow. The third is the environmental improvement of Sabo facilities in urban areas.

The purpose of the first category of Sabo works is to maintain water control functions of the lower reaches of rivers and dams through the conservation of water source mountainous areas coping with the devastation of large drainage basins. That of the second category is to prevent disasters to human lives and properties paying attention to the relatively limited areas.

The third category is the environment improvement works on torrents in urban areas, in which Sabo facilities have already been

installed to some extent. The purpose of this category is to offer to inhabitants playgrounds, recreation fields, and resting places of greenery and clean water through improvement of river beds, plantation, etc.

Sabo Works for Conserving Water Source Mountainous Areas

As mentioned above, there are the wide devastated mountainous areas with a large quantity of sediment, which are represented by the tectonic fractured zones of Central Japan Alps and volcanic calderas of North Japan Alps. The total space of such areas amounts to approximately 53,700 km². Hence, it is one of the key works of national land conservation to maintain and conserve the river control function of lower reaches of rivers through the prevention of outflows of sediment from the devastated mountainous areas and the conservation of mountainous areas themselves.

The ratio of attainment of the improvement of those devastated areas at the end of 1976 was approximately 40%.



Photo 2 Devastation of Mountain Area and Ashio Dam (Watarase River).

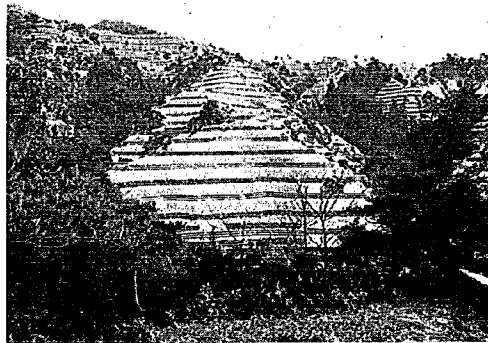


Photo 3 Hillside Work in Tanakamiyama (Yodo River).

Sabo Works as Preventive Measure against Mudflows

As mentioned above, there are approximately 62,000 torrents with the danger of mudflows. The rate of improvement of these dangerous torrents is only 5% at the end of 1976.

As mudflows usually occur suddenly and their destructive force is great, the disastrous damages to human lives and properties are enormous.

Sabo work as a preventive measure against mudflows is one of the important policies of Japan at the present time, and this policy is the pillar of Sabo works.

To be noted is that there are 62,000 dangerous torrents which are too many to be rapidly improved simultaneously.

Under such situations, to save human lives from mudflow disasters, a plan has been made for establishing the system of evacuation of people to safe places before the occurrence of mudflows, setting 1980 as the target year of completion of this plan. It is to determine beforehand the warning rainfall intensity and evacuation rainfall intensity concerning the torrents with the danger of mudflows.



Photo 4 Sabo Dam for Prevention of Mudflow
(Rokko Mountains).

Sabo Works in Urban Areas

As disasters due to mudflows and landslides are considerably increasing in the existing urban areas near mountains such as the Kobe City area or in urban areas which newly expand to mountain feet, Sabo works in these areas are very important and positively promoted.

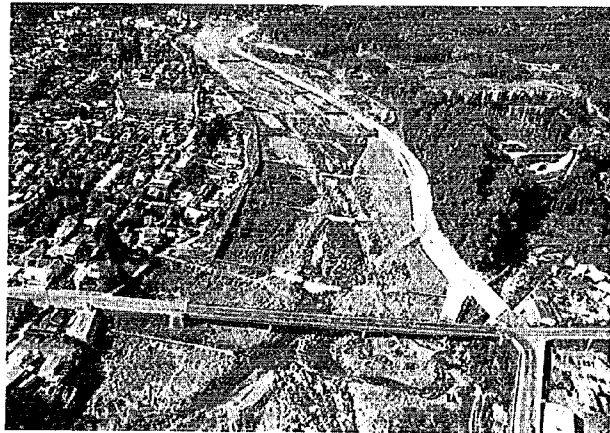


Photo 5 Channel Work for Protection of City Area (Daiya River).

Sabo Works for Prevention of Inflow of Sediment to Reservoir

Many multipurpose dams constructed in water source areas for flood control, power generation, supply of industrial and drinking water, irrigation water are gradually filled with a large quantity of sediment carried down from the upstream reaches of rivers. As a result, it is becoming a serious problem in water resource development or river control.

Sabo works on upstream areas of these dams, therefore, are gaining importance. Actually, they are being done on upstream areas of the flood control dams.

Establishment of Sabo Forest Zone

As a part of the preventive measure of mudflows in alluvial cones,

the establishment of Sabo forest zone around the alluvial cone is planned as an emergency measure. Its purpose is to confine any damages within a restricted area through the dissipation of the energy of mudflows.

Environmental Improvement Works

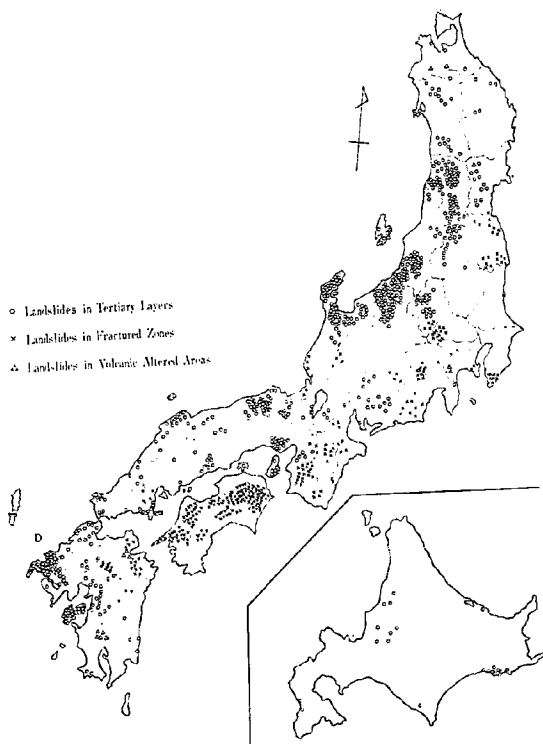
These works are carried out for the torrents in which Sabo facilities have been installed to some extent. Such works offer to inhabitants the recreation places of "water, greenery and comfort" through the improvement of river beds, channels, plantation, etc.

Other Sabo Works

Besides the above mentioned works, there are Sabo works related to the improvement of arable land and development of residential land to be carried out in line with the regional development and improvement. The need of this kind of works is expected to increase.

Landslide Preventive Works

As shown in Fig. 7, landslides occur almost in every part of Japan. Landslide preventive works carried out at the present time stress the greatest importance on those landslides which are considered serious in actual conditions, such as the landslides which devastate the water source areas of large rivers with the drainage basin exceeding 200 km², as they:



Note: Some kinds of soil or weathered rocks in areas of the Tertiary layer, fractured zone or rocks altered by hot spring are easily turned into clay, and soon softened when soaked with water. Such soil sometimes creeps down the mountain slope when saturated with underground water. This is called landslide in narrow sense and distinguished from general landslide.

The damage caused by a landslide depends on its type; Damage of a slow landslide is generally not very big, but sporadic landslides which occur repeatedly over a long period of time may cause much damage when they occur.

Fig. 7 Distribution of Landslide Zones in Japan.

- 1) Cast great influences on Sabo works or river control works in river basins, or
- 2) Have great influences on the conservation of water resources within river basins.

In addition, for landslides locally affecting seriously inhabitants in an area, careful preventive measures are being carried out.

Preventive Measures of Steep Slope Failure

Due to steep slope failures (cliff failures) caused by frequent attacks of typhoons or locally concentrated torrential rainfalls, many human lives and properties have been lost in Japan. Actually, there are approximately 64,000 places in the country endangered by steep slope failures. (The slope height of these slopes is more than 5 m, slope gradient more than 30° and the number of houses for conservation more than 5.) As preventive measures of disasters in such dangerous areas, the system of warning and evacuation for the protection of human beings is the first priority for establishment. At the same time, there must be the promotion of the legal designation of dangerous areas affected by steep slope failures in which all harmful actions are prohibited, the advance of preventive works of steep slope failures by regional governments and the prompt removal of houses near dangerous areas. All these measures are taken to secure safety and welfare of inhabitants and to conserve the national land.

Budget for Sabo Works

The budget of the fifth 5-year plan (1977 financial year~1981 financial year) for Sabo works is 1,070,000 million Yen (excluding preventive measures of steep slope failures).

Sabo Works in Japan and International Cooperation

Together with the progress of Sabo technics in Japan, recently the exchange of information with foreign countries has become very active. The first introduction of such Japanese technics overseas was made in 1966 to Costa Rica on her request. It concerned the disaster prevention investigation of Revendado River against the volcanic mudflow from Irazu Volcano. After the preliminary study for a month, two experts on Sabo works were despatched there to carry out the Sabo works plan of Revendado River. Subsequently, the common recognition of the importance of Sabo works was acknowledged by both two countries. Afterwards, personnel exchange between them has been promoted that has deepened their relationship.

Taking the cooperation with Costa Rica as an opportunity, Japan's Sabo technics made a leap in international technical cooperation. Up to now, such technical cooperation has been expanded to Taiwan, Korea, Indonesia, the Philippines, Guatemala and Nepal. Moreover, the exchange of scientific information has also become active on the other hand. In 1975, an Austrian authority on Sabo works, Dr. H. Aulitzky in the agricultural university in Vienna was invited to Japan to participate in a symposium. Through this symposium, a deeper recognition

of the actual states of Sabo works in the two countries and the technical exchange of information between the two nations were promoted. Actually, exchanges of scientific information are being carried out with many more foreign countries in Europe and the United States, under the leading efforts of researchers in universities and the Public Works Research Institute of the Ministry of Construction of Japan. In July, 1977, International Conference on Soil Mechanics and Foundation Engineering was held in Japan. A part of the activities of this conference included a tour to landslide areas of Japan and a symposium on landslide. These events impressed deeply the participants.

Among the international technical cooperation and information exchange works, the most active ones are related to Japan and Indonesia.

Technical Cooperation and Exchange with Indonesia

Both Japan and Indonesia are well known as volcanic countries, which have suffered every year many disasters from volcanic mudflows. The first technical cooperation with Indonesia was the despatch of an expert on Sabo works to that country in 1970 under Colombo Plan. As of November, 1977, four experts on Sabo works are serving as senior advisers in Directorate General of Water Resources Development, Ministry of Public Works and Electricity, Indonesia, contributing to the finding of measures against volcanic mudflow, prevention of slope failure, mudflow and landslide, and prevention of disasters caused by sediment on river bed above ground level and on alluvial cone. They, of course, enjoy the close cooperation of their Indonesian colleagues.

In 1976, two major projects between Japan and Indonesia were commenced. One is "Investigation for the Establishment of the Basic Plan of Sabo Works of Merapi Volcano" which is located at the north of Yogyakarta City in central Java, and the other is the commencement of "Cooperation in Research on Sabo Works in Volcanic Regions of Indonesia and Japan."

The purposes of the former project are for the establishment of preventive measure of mudflow from Merapi Volcano and the development and effective utilization of irrigation water supply in the central part of Java where the Indonesian population concentrates, and where the land is densely utilized. For this project, the disaster prevention plan of Yogyakarta Special City and its surrounding areas is the base of the regional plan, and it is highly evaluated by both the two countries. Investigations are to be carried out for four years under the sponsorship of Japan International Cooperation Agency.

The "Cooperation Research on Sabo Works in Volcanic Regions" was started with the special overseas research funds of the Ministry of Construction. Its purpose is to draft technical criteria on measures against volcanic mudflow by March, 1979, through observations of volcanic mudflows in both countries, exchanges and analyses of data, exchanges of researchers and holding of a symposium. The mudflow observation instruments have already been sent to Indonesia from Japan. The exchange of researchers is taking place in the second year. Thus, this "cooperation research" is being carried out on the full scale.

Technical Cooperation with The Philippines

Japan's technical cooperation with the Philippines in full scale began in 1977. The main feature is the investigation for the establishment of flood control and Sabo works in Pasig-Potoreto River which is a tributary of Panpanga River in Luzon Island. This investigation will last till June, 1978 for about a year. Besides, the investigation on the measure against mudflow from Mayon Volcano at the southern end of Luzon Island is expected to start.

Technical Cooperation with Nepal

With respect to the prevention of natural disasters in Nepal, such as flood, mudflow, slope failure, landslide, etc., Japan's contribution to Nepal in preliminary studies was carried out in April, 1977 through the despatch there two specialists on the prevention of natural disasters. In September of the same year, a specialist on Sabo works was sent there as a technical adviser for a year by the coordination of UNDRR. Thus, through this kind of cooperation, the strengthening of friendship between the two countries is greatly expected.

Technical Cooperation with Other Countries

Upon earnest request of Guatemala, three Japanese specialists on Sabo works were despatched to that country in March, 1976 for a month to work out the emergency measure as well as the long-term plan for the prevention of collapse and landslide in Shirace Terrace where is the deposit of special volcanic ash soil.

In September, 1977, a specialist was sent to Korea for two weeks to carry out the investigation for the prevention of slope failures and mudflows.

In carrying out technical cooperation with foreign countries, it is desirable to proceed without haste, and thorough exchange of mutual standpoints as well as common recognition must be adequately obtained.

Organizations in Japan Supporting Sabo Works

The Erosion Control Engineering Society

This society supports Sabo works in Japan in the field of science. It was founded in 1947 and is now composed of approximately 2,000 members of various backgrounds, such as researchers in universities, engineers of the Ministry of Construction or the Ministry of Agriculture and Forestry, researchers in various laboratories, engineers of regional governments active in such works, and engineers of consulting companies.

The major activities of the society are the general meeting and the conference for the announcement of researches and the publishing of research documents once a year, a symposium once every autumn, the publication of the journal "New Sabo" four times a year, the compilation of technical dictionary on Sabo, and the compilation of the list of universities and research institutes concerning Sabo works.

Its address is as follows:

Secretariat: Secretariat of The Erosion Control Engineering Society
Sabo Kaikan, 2-7 Hirakawa-Cho, Chiyoda-Ku, Tokyo
President: Yoshio Yano, Dr. Agr.

The Japan Society of Landslide

This society has played an inestimable role in the development of science and technology in the field of prevention of landslide. It was founded in 1963 and is now composed of approximately 2,000 members who are of various backgrounds in a wide field, including geologists and specialists of soil mechanics.

Its major activities are the general meeting and the conference for the announcement of researches and the publishing of research documents once a year, holding of symposium, and publication of journal four times a year.

Its address is as follows:

Secretariat: Secretariat of The Japan Society of Landslide
2-21-2, Egota, Nakano-Ku, Tokyo
President: Kenzo Sasa, Dr. Sci.

Sabo Technical Center

This center is a foundational juridical person.

Conservation of national land, and conservation and maintenance of natural environment are the fundamental tasks of a modern country, which can be only attained through having Sabo works as the nucleus. The role of Sabo works is also important to the maintenance of water resources. In order to establish the application system of technics relating to Sabo works, it is necessary to assemble technics of Sabo works through utilizing the most of human knowledge and experience in various fields.

It carries out the investigation into problems of Sabo works and preventive measures against landslides and slope failures through the function of its committee which is composed of men of knowledge and experience. Besides research and planning works in Japan, for international technical cooperation, it has conducted investigations on Sabo works in and with Indonesia and the Philippines.

Its address is as follows:

Office: Seisen Ichigaya Building, 4th Floor
3-4 Ichigayasadohara-Cho, Shinjuku-Ku, Tokyo
Representative: Fukusaburo Toda

National Sabo Association

This association is a corporate juridical person.

It was founded by the late Dr. Masao Akagi, known as father of Sabo works in Japan. Its office is now in the "Sabo Kaikan" which was also established by the doctor.

The functions of the association are the investigation into methods necessary for Sabo works, the promotion of public recognition of Sabo works, and the prevention and reduction of disasters through the promotion of Sabo works, so as to contribute to social welfare. To

attain these purposes, the association carries out the following mentioned works through setting up branches in the regional governments of Japan:

- Investigation and study on matters concerning Sabo works
- Propaganda of Sabo works
- Recommendation and reply to public agencies on Sabo works
- Communication with related people on Sabo works
- Any other relevant tasks related to Sabo works.

Its address is as follows:

Office : Sabo Kaikan
2-7, Hirakawa-Cho, Chiyoda-Ku, Tokyo
President: Eiichi Nishimura

National Conference of Landslide Control

The functions of this conference are to elevate the technical level of its members and to advance prevention works of steep slope failure and landslide through investigation, study and announcement.

Its office is set in the Sabo Division of Civil Engineering Department, Nagano Prefecture, and its branches are laid in the regional governments of Japan.

Its president is the governor of Nagano Prefecture.

ii) INFORMATION ON THE DEBRIS FLOW DISASTER IN MT. IWAKI

AND

IT'S IMPROVEMENT PLAN

T. MATSUSHITA

1. GENERAL INFORMATION

(1) Debris Flow Disaster

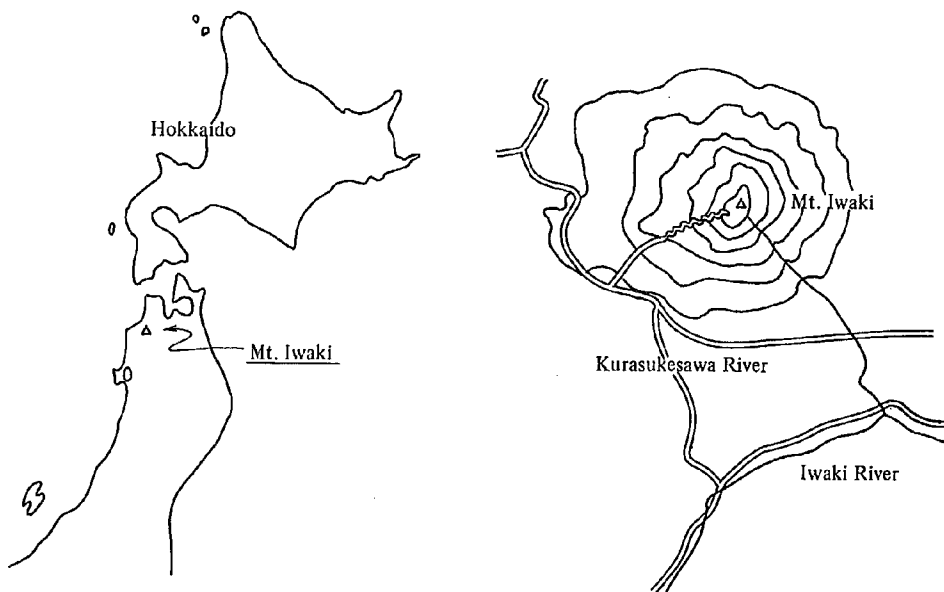
Debris flow, which occurred in Kurasuke river of Mt. Iwaki in Aomori Prefecture, attacked Momosawa village in the early morning of August 6, 1975.

The damages were described below.

The dead	22 persons
The wounded	31 persons
The houses destroyed	26 houses
The houses inundated	36 houses
The inundation of cultivated fields	16 ha

The heavy and concentrated rainfall from August 5 to 7 in this area caused this tremendous debris flow and, this was the worst record of damages in Aomori Prefecture ever experimented.

(2) Location



(3) Geology, Topography and other conditions in the Area

Mt. Iwaki is a compound volcano of conoid type, the last gas eruption of which was 1863 and is located at south-eastern part of Tsugaru plain of Aomori Prefecture, northern part of Honshu Island and, the height is 1625 m above the sea level.

The gradient of mountain slope is more than 30 degree between the top and 1000 m height and 15–30 degree between 1000 m and 500 m height and, less than 8 degree below 500 m and gradually transfer to the fan of the mountain-foot.

The mountain slope is considerably developed into many radial torrents from the top to mountain-foot and, Kurasukesawa river is one of these radial torrents.

As regards geology, the mountain is composed of Quartz-andesite around the top and, alternation of strata of Andesitic-lava and Andesitic-agglomerat in the middle part of mountain slope and, accumulation of volcanic detritus in mountain-foot.

The gradient of river bed of existing Kurasukesawa river is extremely different between the distance from the top to No. 2 Sabo Dam and that of lower part of No. 2 Sabo Dam. The former is 15–30 degree and the latter is 5 degree on an average, except the distance from the upper part of No. 1 Consolidation Dam and No. 3 Consolidation Dam. The distance mentioned above forms steep V valley and the gradient of river bed is 8.2–8.5 degree which is rather steep than that of average.

The length of the river is about 6 km and the catchment area is 1 km² in the upper part of No. 3 Consolidation Dam. The length means the distance from the top to the prefectural road of Hirosaki-Ajigasawa.

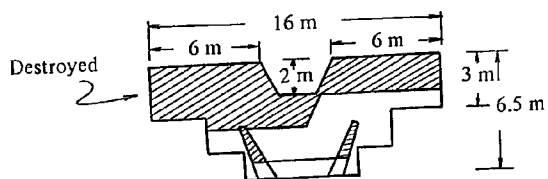
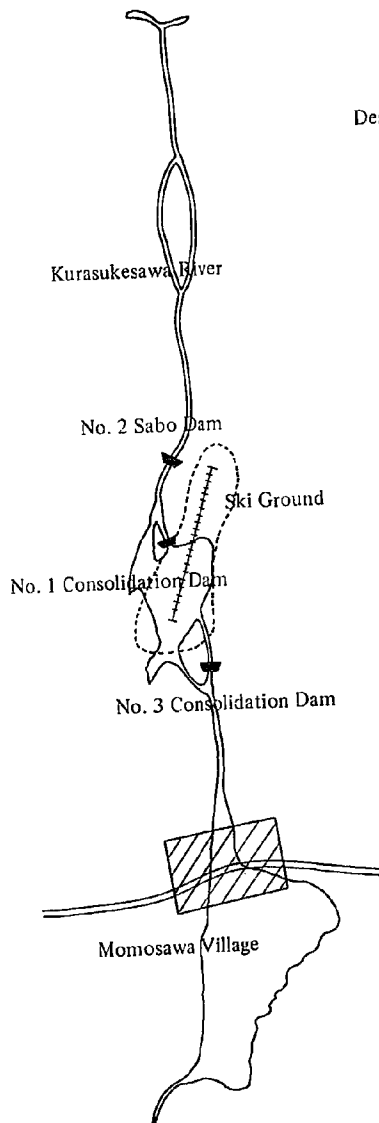
As regards the vegetation in the area, the area of Kurasukesawa river is covered by woods of *Quercus crispula* (Japanese oak — Mizunara), *Fagus Sieboldi* (Buna), *Alnus Japonica* (Miyamahannoki) and other flora of temperate zone.

(4) Rainfall in the Area

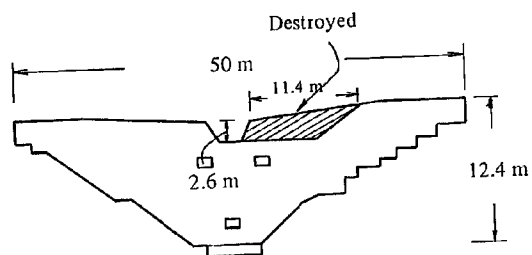
There is no rainfall recorder in Mt. Iwaki, therefore, Mr. Narita, the Head of Aomori Meteorological Observatory, presumed as follows.

Total amount of rainfall	100–150 mm
Maximum amount of one hour rainfall	60 mm
Maximum amount of ten-minute rainfall	20–30 mm
(around 3 o'clock on August 6)	

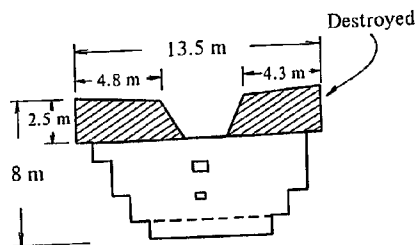
2. SABO STRUCTURES AND SKI GROUND



No. 1 Consolidation Dam

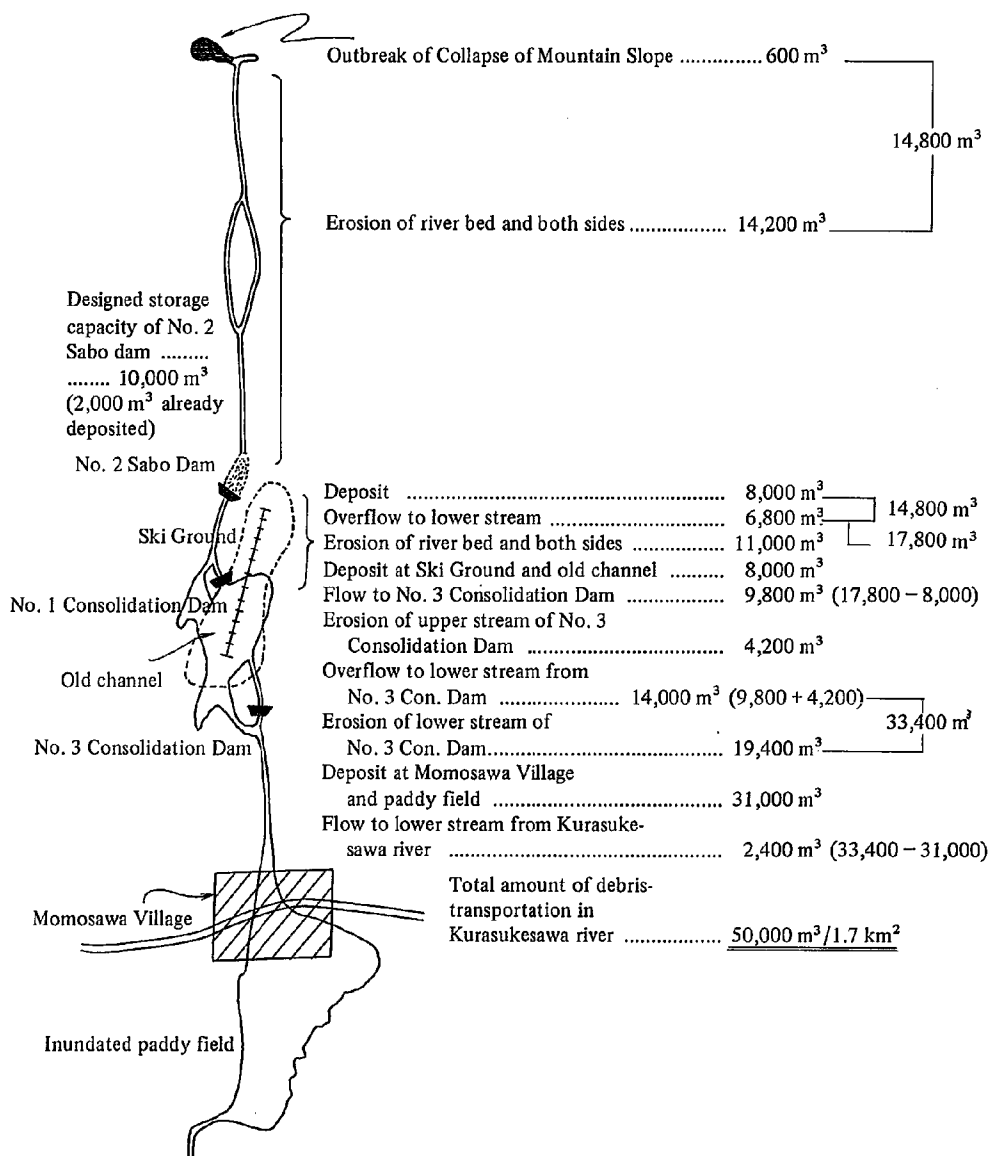


No. 2 Sabo Dam

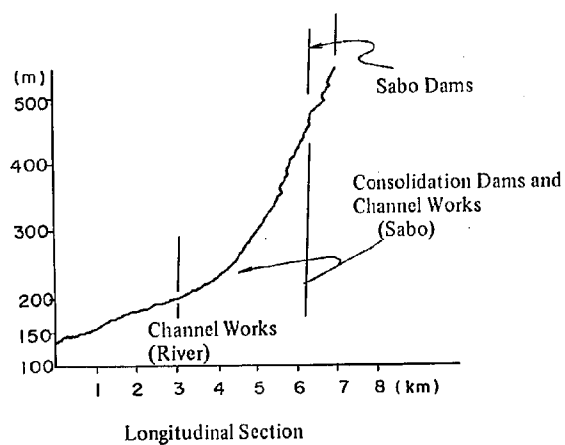
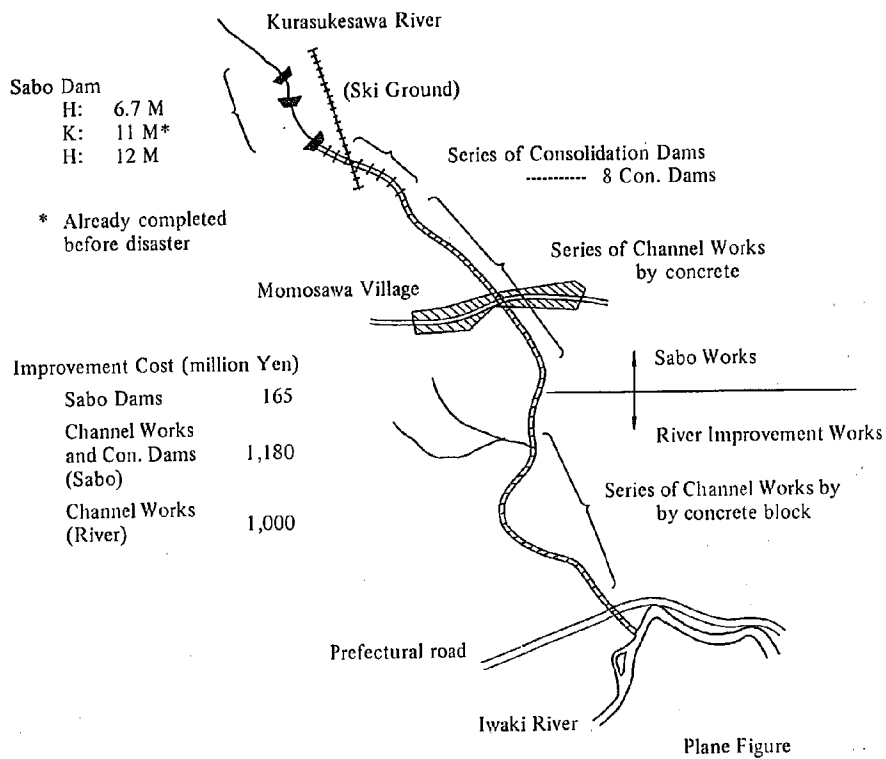


No. 3 Consolidation Dam

3. COLLAPSE OF MOUNTAIN SLOPE AND DAMAGE OF KURASUKESAWA RIVER



4. RESTORATION AND IMPROVEMENT PLAN OF THE AREA



5. COUNTERMEASURES FOR FUTURE STABILIZATION

(1) Implementation of restoration and improvement works

The works mentioned in part 4 should be completed as early as practicable. These works were already completed in 1977 fiscal year.

(2) Set-up of Dangerous Area of Debris Flow

The set-up of dangerous area of debris flow is absolutely necessary for the future stabilization in this area fully taking into consideration of turbulent phenomena at the top of its alluvial fan and future direction of stream channel.

(3) Clear Indication of Evacuation Place

Public meeting hall, school, hospital, shrine, temple or personal houses which are clearly and absolutely free from danger of debris flow should be designated as the evacuation place in the area.

(4) Installation of Rain-gauge

At least, one rain-gauge should be installed in every community in a village for recognizing rainfall information.

(5) Conveyance of Warning Information

Various kinds of warning instruments including wireless walkie-talkie should be arranged in every community of the village.

(6) Set-up of rainfall-amount for evacuation

(7) Establishment of Warning and Evacuation System in the Area

(8) Promotion of Consciousness of Self-Evacuation of people

The fundamental idea mentioned above should be applied in every places of Japan as a common programme which should be promoted from now on.

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Tokyo, March 1978

(T. MATSUSHITA)

3. PROCEEDINGS OF DISCUSSION

Part — 1

Japan — Indonesia Symposium on Volcanic Debris Flow Treatment Discussion

1st Day, March 27, 1978

Chairman ; Mr. M. WATARI (P.W.R.I)

” ; Ir. Surajil (Indonesia)

Secretary ; Mr. H. IKEYA (P.W.R.I)

Interpreter ; Mr. H. KUMAGAI (Japan Translation Center, LTD.)

Chairman;

Gentlemen, now I would like to begin the today's discussion. For this discussion you may use either English or Japanese, and Japanese speaking will be translated into English by interpreter so please speak very slowly.

Now, I would like to accept your question regarding to the lectures we had today.

At first, I would like to have your question regarding to lecture made by Mr. Suryo this morning.

Mr. Yoshioka (P.W.R.I.);

I want to make some questions to Mr. Suryo regarding to the Nuée Ardente.

At first, I would like to know the thickness of volcanic sediment which is caused by Nuée Ardente.

Secondly I want to know the grain size of sediment caused by Nuée Ardente. Thirdly I want to know how long the sediment of Nuée Ardente will take to flow away after a rainfall.

Mr. Suryo;

I would like to answer the questions. For first question regarding to the sediment caused by Nuée Ardente, I should say that in an eruption of Merapi in 1961 the thickness was more than 50 meters. For other volcanic eruptions we also have similar thickness.

The biggest one is about 60 m at G. Agum. Generally, avalanche type is not so thick, ordinarily it's about 1 m or so, and eruption type is so thick mentioned above.

For the second question, the size of Nuée Ardente material is very fine, and for the third question, ordinarily, the sediments of Nuée Ardente remain untill next rainy season.

Mr. Nakayama (Kokusai Kogyo Co.);

I would like to ask to Mr. Suryo regarding to Indonesian word "Ladu". Can this word "Ladu" be used for sediment both in motion and still?

Mr. Suryo:

Indonesian word "Ladu" is used for the incandescent flow of volcanic debris, and when we use word "ladu materials" it has meaning of ladu material not necessarily in motion.

So, we use the word "Ladu" both in motion and still in Indonesia.

Dr. Okuda (D.P.R.I of Kyoto Univ.);

I would like to know the height of cloud of avalanche type Nuée Ardente.

Mr. Suryo;

Height of cloud of avalanche type Nuée Ardente is generally up to 2000 meters.

Dr. Takei (Kyoto Univ.)

I want to ask to Mr. Suryo about effects to the forest.

How the forest on western slope of Mt. Merapi is affected or broken by lahars?

Mr. Suryo;

The forest have no utility of defense for Nuée Ardente, because Nuée Ardente has a destructive power and high temperature.

In the western slope of Mt. Merapi, there are many pines, but it's not so useful for the stopping of Nuée Ardente, I think.

Mr. Matsushita (M.C);

Does the word of "Awan panas" has the same meaning as Nuée Ardente in Indonesia?

And, I want to know what shape of Nuée Ardente front edge is. Lastly, what is the stop condition of Nuée Ardente, especially, what is slope inclination of stopping?

Mr. Suryo;

We use the word "Awan panas" with same meaning of Nuée Ardente.

About next question, we have a case that Ladu stopped at the 10 degrees slope about 13 km far from the summit. And for the shape of Nuée Ardente, perhaps, it has same shape as it do when it flows down at the fan.

Mr. Watari (P.W.R.I);

I understand that the arriving distance of Nuée Ardente is determined by shape or configuration of land.

But if you have a mountain or sabo dam which is about 20 to 30 meter high within a valley, do you think that the arriving distance of Nuée Ardente could be reduced?

Mr. Suryo;

Sabo dam is no use for reducing arriving distance of Nuée Ardente because Nuée Ardente has a distractive force within 13 km from summit at G. Merapi, so perhaps, sabo dam will be broken within such area.

Chairman;

Now I would like to receive questions regarding to lectures made this afternoon.

Mr. Watari;

Mr. Yoshioka has already mentioned about various characteristics of mudflows. But now I am wondering whether you have information on physical properties of mudflow materials such as grain size, consistency and shear strength and so forth.

Mr. Yoshioka;

As far as my past investigation is concerned, some of grain size was as large as 5 to 6 meters in diameter.

As far as I know, the shear strength of mudflow material is rarely measured.

However, by using sample collected in the cylinder which was placed at the sleeve of sabo dam, simple shear testing method can be utilized if shear strength is required to be measured.

As far as consistency is concerned, the material sampled within a cylinder placed in the sleeve of sabo dam can be measured for consistency but I don't have the data.

By investigating deposit of mudflow at the site where mean grain size is from 17 to 19 cm, the ratio in weight between gravel larger than 20 cm and smaller than 20 cm was about 0.63 though this value may vary depending upon various conditions.

If specific gravity of stone is assumed to be 2, the void ratio is about 33% in this case.

Mr. Ikeya (P.W.R.I);

I would like to ask to Mr. Yoshioka. In your lecture, you have been using both terms debris flow and mudflow. When we talk about Indonesia, which term is more close to term lahars in its meaning in your opinion?

Mr. Yoshioka;

As far as my lecture is concerned, I was considering to make no difference between debris flow and mudflow in my lecture.

In my opinion, term "mud flow" may have broader meaning compared to the term debris flow.

In my opinion, in Japan, once-deposited materials frequently flow down in many cases so that I feel that term "debris flow" may be included within the category of mudflow. However, making definition for the difference between mudflow and debris flow is usually very difficult to do.

Mr. Ikeya;

I want to make another question. Regarding to technical term of mudflow or debris flow, I am wondering how the results of our studies or of this symposium can be applied to the lahars of Indonesia in view of this difference in technical terms.

Mr. Yoshioka;

In studying the debris flow in Japan, we have to know that the frequency of occurrence of debris flow is very high particularly for volcanoes including dead ones.

So, studying of debris flow is actually equal to studying of volcanic debris flow.

However, we gradually know that there are two types in debris flow. One type has boulders concentrated at its leading front edge of debris flow and other type has a tendency to flow as a hydraulic bore at its head portion.

As far as type of debris flow in Indonesia is concerned, I suppose, it is more like hydraulic bore in view of data I obtained up to now.

So, characteristics of debris flows with this hydraulic bore as observed in Japan may be also applied to the debris flow occurring in Indonesia since their properties are very close each other.

All I talk about up to now are mainly related to the design of sabo dam, but as far as origination of debris flow is concerned this must be considered separately.

Ir. Bambang (INDONESIA);

Explanation by Mr. Yoshioka is very interesting to us, especially the studies being made on the mudflow in your country. I listened to the method of sampling of mudflow using 10 cm cylinder, and I have heard about Mt. Sakurajima and Mt. Yake as well as the movement of mudflow.

Now my question is how to fix the sample by the cylinder. Secondly, because diameter of cylinder is 10 cm, boulders larger than 10 cm can't be caught by the cylinder. How the size of such boulder is determined?

My third question is concerning to the relation between rainfall and debris carrying into the river.

Mr. Yoshioka,

Now, there is no way to measure for the flowing mudflow both clay and boulder at the same time by a single method.

So, we use the two methods, one is a method of measuring using cylinder, and another is a method for measuring mudflow that stopped or is not in motion.

The former is mainly for the fine grain size and the cylinder is buried on sabo dam. The latter is for large grain size.

Ir. Bambang;

Regarding to the cylinder, is the debris flow in this cylinder picked up repeatedly one by one?

Mr. Toshida (Osumi Construction Office, M.C.);

For sampling the material, we sampled mudflow afterward every time it passes by the cylinder. This means we measure several times instead of once.

Ir. Bambang;

At one flood, how many times did you repeat the sampling? I mean, how many minutes for first sampling and how many minutes for second and so forth?

Mr. Toshida;

In our survey, we measure several times by the sampler and the interval is about 15 to 20 minutes.

And, I will give you details later.

Dr. Okuda;

I think the measurement of distribution of grain size is very difficult problem, but it's very important.

So, it's preferred to sample the various grain sizes which the mudflow is actually in moving state.

For sampling small grain size, the cylinder we are using at Yakedake has 12 cm diameter and height of 15 cm.

For measuring larger size, it will be desirable to measure it by taking pictures while the mudflow is falling down from sabo dam which is shown in this text.

When using 35 mm camera with high resolution, you can find accurately the distribution of boulders which

are greater than 15 cm.

However, this cylinder will be too small for measuring boulder larger than 10 cm. So I think sampler size should be rather increased to 20 cm in diameter. If both methods are used in combination, all grain sizes can be covered by this combination method.

As far as a sampler of Sakurajima, at present time, it will be very difficult to sample the materials at certain interval unless someone goes to the site.

So right now, we are considering and studying to have automatic sampler system which will be able to sample the material consecutively by putting the samplers into the moving mudflow.

Ir. Bambang;

I want to know measuring method of materials which is not in motion.

Mr. Yoshioka;

For small grain sizes we use sieves and for larger one we use some log-measuring device to measure the diameter of boulder.

I tried to give you information on size of hole or excavation for sampling but I have no reference books here. So I will give you some information to you later.

Chairman;

It is very close to our closing time schedule. And I will close today's discussion now. The questions to two other lecturers will be received tomorrow.

Thank you very much for your attendance. Now first day of this symposium will be closed. Thank you.

Part - 2

2nd Day, March 28, 1978

Chairman	;	Mr. M. WATARI	(P.W.R.I)
"	;	Ir. Surajil	(Indonesia)
Secretary	;	Mr. H. IKEYA	(P.W.R.I)
Interpreter	;	Mr. H. KUMAGAI	(Japan Translation Center, LTD.)

Chairman;

Yesterday, some parts of questions by Mr. Bambang to Mr. Yoshioka have remained. And today we would like to begin our discussion from that question. Mr. Bambang would you kindly repeat that question you made yesterday.

Ir. Bambang,

Gentlemen, thank you very much for the opportunity of question time. Yesterday, I had three questions. The first question was about the technical method how to catch the certain sample that was answered and I have understood, the second one was about boulders how to measure the boulder size but I am not clear as yet because question has to be answered within the limited time. My third question was about relation between the intensity of rainfall and debris carrying onto the valley or onto the river.

Mr. Yoshioka;

As far as relation between the rainfall intensity and occurrence of mudflow is concerned, this is indicated in the text book (Fig. 3~5). And you can see the arrows. These arrows indicate the time of mudflow occurrence.

The occurrence of mudflow may be not only one but may be twice or three times even after a single rainfall. According to this figure, the mudflow actually occurred only during heavy rainfall or immediately after heavy rainfall. Only such conditions are shown in this figure.

Different geological conditions are also included in this figure.

We tried to have the same geological condition in this analysis figure but we had the same results.

But at area where we observed volcanic mudflow, slightly different characteristics were found.

In case of Mt. Yakedake, the mudflow occurs at a probability of 60% if the maximum hourly precipitation is higher than 11 mm and the continuous precipitation reaches 20 mm or more.

And next, I will show you the case of Mt. Sakurajima. Normally mudflow do not occur if the effective rainfall intensity is less than 4 mm per hour. It is also believed that such mudflows do not arise when the effective rainfall is below 40 mm. In the case of Sakurajima, however, there have occurred such extraordinary phenomena that the incidence of mudflows is so high as 80% when the effective rainfall was below 40 mm and that several cases of mudflows have occurred even when the effective rainfall intensity was below 4 mm.

I am going to conclude my answer but I am wondering if this is enough for you, Mr. Bambang?

Ir. Bambang,

In Fig. 4, relation between accumulative rainfall and mudflow is shown. But while I am questioning regarding to relation between rainfall intensity and mudflow occurrence, I would like to know the meaning of accumulative rainfall. Expression "accumulative rainfall" differs from the expression of rainfall intensity. Is this figure is correctly indicating the relation between mudflow occurrence and rain?

Mr. Yoshioka;

This accumulative rainfall intensity is actually the result of hourly rainfall which were added up.

Therefore, if slope of this curve is steeper this means that the intensity of rainfall is also higher or stronger. Horizontal portion of the curve indicates stop of rainfall for a while for certain hours. Therefore, you may probably understand the relationship between time of mudflow occurrence and type of rainfall also from this figure.

Ir. Bambang;

Thank you.

Dr. Takei;

I happened to have some information regarding to the problem of rainfall discussed just now. We, the members of our laboratory, are studying this problem by use of tank model which is a method to analyze runoff and rainfall. In our study, if first or second tank is filled with some distilled water, the occurrence of mudflow is very possible. I think I can supply you the paper on this matter later but it is written in Japanese, I am sorry.

Ir. Bambang;

What do you think about precipitation and runoff?

Dr. Takei;

Regarding to the relation between precipitation and runoff in that model, I can estimate thoroughly the mountain area, then I can judge the occurrence of mudflow by the third capacity.

Chairman;

Mr. Bambang, do you have enough information?

Ir. Bambang;

Yes, thank you.

Chairman;

Now, I would like to accept any question regarding to lectures by Mr. Bambang and Mr. Yamauchi.

Mr. Yoshioka;

I would like to ask question to Mr. Bambang. The material given to us by Mr. Bambang indicates the velocity of mudflow in page 7, the material we received yesterday.

I would like to know the method of measuring of velocity and also the river bed gradient.

Ir. Bambang;

Velocity was measured by observing floating materials such as wood, using stop-watch. Gradient was measured by leveling but, to my regret, I have no data in my hand right now and I will mail them to you later.

Mr. Yoshioka;

When you will give me the additional information, I would like to have also the information regarding to the maximum water level.

Ir. Bambang;

Regarding to the maximum water level, unfortunately in my country we don't measure the water level.

Mr. Nakayama;

I remember some information regarding to the mudflow velocity and water level which were indicated in the report made by Mr. Schmit in 1934.

Mr. Yoshioka;

When I compare the values of impact force at Indonesia with the values obtained from measurement at Mt. Yake. The values of Indonesia are relatively small.

I imagine that large stone did not attack the measuring devices.

So, I would like to know about mudflow regarding to its size, which was observed for this test and accumulated in lower reach. I am especially interested in the grain size of materials in the mudflow.

Ir. Bambang,

Regarding to the question of the test in Indonesia, I would like to inform that the most of materials in Mt. Merapi are fine materials as probably informed by Mr. Suryo yesterday, or this morning.

In Indonesia, the data from the impact pressure meter show the smaller values, but in my opinion, they are correct. In my opinion in Sakurajima, boulder is affecting to the data measured by impact pressure meter.

Mr. Yoshioka;

Then, I am wondering that the scale of mudflow itself is not actually small there but the grain size itself is rather smaller in Indonesia compared to that in Japan. Can I think that this is correct?

Ir. Bambang;

Yes, you are correct.

Chairman;

I would like to receive questions regarding to the lecture made by Mr. Yamauchi.

Chairman;

No question? Then I would like to receive questions regarding to today's four lectures. At first, please make questions regarding to Dr. Okuda's lecture.

Mr. Suryo;

I would like to ask Dr. Okuda about testing made at Kamikamihorizawa. I would like to know about instruments used for testing the vibrations.

Dr. Okuda:

We used simple seismometer for geophysical survey or geophysical prospect, which is a simple portable instrument. This produce artificial vibration by hammers.

Mr. Suryo;

Is this a kind of seismograph?

Dr. Okuda;

Yes.

Mr. Suryo;

I would like to know the constant of the seismograph, such as magnification.

Dr. Okuda;

I don't have the data now but I would send them to you later. Now we are measuring by use of micro-seismograph constantly placed along the bank.

Mr. Suryo;

Where do you put the seismograph, I mean how far from the valley?

Dr. Okuda;

I put seismograph about 3 meters from the bank. And it automatically turns on when front of debris flow reaches to the device. At a place about 50 meters from there, the vibration is automatically recorded.

Mr. Suryo;

Is this then continuously recorded?

Dr. Okuda;

Yes it is set permanently.

Chairman;

Now I would like to receive question regarding to Mr. Suryo's lecture.

Mr. Nakayama;

I would like to ask Mr. Suryo regarding to lahars in Indonesia. As far as I know, term lahars is being used only for the volcanic mudflow. But I am wondering if this term can be also used for non-volcanic

mudflow. Also, I want to know the example of unvolcanic mudflow.

Mr. Suryo;

What we used to say about lahars is for volcanic mudflow, and for mudflow not from the volcanic origin we don't use term lahars.

Mr. Nakayama;

Word mudflow in Japan is containing also non-volcanic meaning, and if technical term lahars is used internationally, I think that the word debris flow must be clarified or defined.

Mr. Suryo;

In Indonesia, as we have already mentioned before, lahars is water flow mixed with volcanic mud and debris of all dimensions, and if mudflow occurs in non-volcanic area, we just call it mudflow. Term lahars is used for flow from volcanic origin. Therefore, kind of lahars which is actually mudflow from non-volcanic area is just called mudflow.

Dr. Okuda;

I want to make some questions. According to the data of this text, 75 mm rainfall is taken at 35-minute interval. And I want to know why the interval of 35 minutes was used in the test.

Usually we use, for example, 10 minutes or hourly rainfall intensity. But why did you use 35-minute intensity in your country?

Mr. Suryo;

This is according to the warning system. We used electric automatic rain gauge for which 35 minutes was possible to fit and good for reading. This is why we used this interval.

Dr. Okuda;

Now I know the seismograph is being used in warning system in Indonesia. And I am wondering if this seismograph is used for earthquake or for measuring debris flow?

Mr. Suryo;

We use seismograph for earthquake measuring naturally with high sensitivity. For lahars warning we use seismograph with low sensitivity with magnification of about 150 and quite long period of about 4 seconds.

Dr. Okuda;

I would like to know the main periods of seismograph.

Mr. Suryo;

Period of seismograph for volcanic earthquake is 1 sec. with magnification of 2000, while for lahars warning system we use 4 seconds with magnification of 150:

Mr. Maruyama (Asia Kosoku Co.);

I want to ask to Mr. Suryo. At first, I would like to know how did you get the data which you showed in Table 1. I think that it is quite difficult to get this kind of data because the oldest datum of eruption is in 1826. I want to know the source of this datum. Where did you get this datum?

Mr. Suryo;

These data were obtained from weekly bulletin and confirmed by a professor at Volcanological Survey Institution.

Mr. Maruyama;

I understood. Now I want to ask a next question. Generally in bulletin, somebody collects data and put them in the bulletin but in Japan some bulletin shows volcanic eruption occurred even in 17th century. And I am always wondering why they get such good data even in old time. Therefore, I want to know if it is possible to get some other information concerning to volcanic eruptions in your country. If possible, I would like to know the distribution of lahars and damaged area.

Mr. Suryo;

We have data of eruptions which occurred before 18th Century in Indonesia but they are not reliable so that I don't put them in the table.

Mr. Maruyama;

Usually we call lahars for every mudflow relating to volcanic materials. Do you call "lahars" even for those which do not cause troubles to human life? Because some lahars shown in beautiful pictures inside of the gorge which you took from a bridge and showed to us, seems to do no hazard to human life. But do you still call it "lahars"? I thought that we can call it lahars only when it gives some dangers to human life or makes hazard to us.

Mr. Suryo;

Actually even when no people is missing, we call it lahars if lahars flows in an area.

Mr. Yamauchi (P.W.R.I);

I would like to ask a question regarding to the leading edge of lahars in Indonesia.

In Japan when we think of leading edge or head of mudflow, we usually think a shape of surge. In Indonesia, do you see the same surge or hydraulic bore at the head of the mudflow?

Mr. Suryo;

I believe that it is almost the same as that seen in Japan.

Mr. Mizuhara (Mie Pref.);

As far as I know, as I observed some actual mudflow in Indonesia. I thought that the shape of surge is

slightly different from the one we have in Japan. In Indonesia, the peak portion of the surge is located slightly behind the front edge of the mudflow.

Chairman;

Since we don't have sufficient time, I would like go to next one. Now, please make questions regarding to Dr. Takei's lecture.

Ir. Bambang;

Regarding to lecture made by Dr. Takei, I would like to know more about Fig. 4.

Dr. Takei;

(He explained about gradients and altitudes in the figure.)

Mr. Bambang;

Now I understand, thank you.

Chairman;

Any other question?

Mr. Mizuhara;

I would like to ask question to Dr. Takei regarding to Progo River. The tractive force of Progo River is very large and therefore the sediment of K. Krasak River should soon flash out to Progo River. This is your comments made in your lecture. Do I remember correctly?

Dr. Takei;

Yes, that is my imagine for K. Progo.

Mr. Mizuhara;

Indonesian government is worrying about sedimentation of K. Progo. Expecially, there is an intake for drainage at Bandol down part of K. Progo, and in that site, the river bed is rising now.

So, I think we must consider this problem.

Dr. Takei;

My idea was actually brought to me when I considered this large amount of yield sediment. And this sediment must be removed at some place anyway. In this case, it will be much easier to let the fine materials flow into the lower reach because this will be more advantageous in view of dredging cost and cost of transportation. This is why I thought of letting the fine material flow into the lower reach. But I wonder that my idea may be a result of my inexperience.

Mr. Mizuhara;

I have another question. Mr. Yoshioka pointed out yesterday that the gradient of river bed where lahar flows stopped is 5 degrees. But Dr. Takei stated today that there is a possibility of lahars flow even at 3-degree gradient. So, I want to ask Dr. Takei if lahar flows in Indonesia may differ from the mudflow seen in Japan.

Dr. Takei;

I think that 5 degrees of slope inclination will be generally very difficult to stop the lahar flow. In Indonesia, we have the data that the lahar flowed down even the bed slope is 2%, and it stopped about at 1 degree bed slope. But, I wonder if it is the same mudflow as seen in Japan or not. Now, I think about the flow where flow itself may have no such a high density as Bingham flow. Recently, Dr. Takahashi, associate prof. of Kyoto Univ., expressed the experimental test data for mudflow, but I think we must consider more low density flow of elasticity.

Chairman;

Since we don't have sufficient time, now I like to receive questions to Mr. Matsushita.

Ir. Surajil,

I want ask questions to Mr. Matsushita. I understand that there are three dams, No. 1 consolidation dam, No. 2 sabo dam and No. 3 consolidation dam in the Kurasakesawa River.

I wonder why the location of the sabo dam was selected to this place. Secondly, in Indonesia we call "consolidation dam" if its height is less than 6 m and we call "sabo dam" if height is greater than 6 m or so. I want to know why this is different in Japan. Thirdly, regarding to consolidation dam No. 1 and No. 3, which dam is to be considered as key dam?

Mr. Matsushita;

I would like to answer the questions made by Mr. Surajil very briefly and clearly. At first, the location of No. 2 sabo dam was decided, I suppose, because it had a big sand pocket for storage. Second question was concerning to the height of consolidation dam and sabo dam. When we use sabo dam of consolidation dam, we should consider the functions of the structures. The consolidation dam should not be expected to store the sand materials. Its functions are to consolidate and protect the erosion of the river bed. These are the functions of the consolidation dam. So we did not expect any sand storage function at No. 1 and No. 3 consolidation dam sites. These should be decided according to the functions of sabo structures. So, we should expect the same storage functions to the sabo dam. Thirdly, concerning key dam, it is very difficult to answer briefly. Please open page 5 of my text. The key dam should be the lowest sabo dam which was constructed at upper part of the Kurasakesawa River. We constructed three sabo dams there. So the lowest sabo dam should be considered as key dam.

Chairman;

Now we are going to close the discussion of today. Thank you.

4. CLOSING ADDRESS

Chairman of the Symposium

Mr. Masasuke WATARI

(Geotechnical Director, P.W.R.L.)

I am very glad that this symposium finished very successfully by cooperation with Mr. chairman Soeradjil and all of the participants. I think the result of this symposium is estimated very highly and is much useful to progress of the joint study of debris flow treatment of both countries in future.

The next symposium will be opened in Indonesia one or two years later. At that time some Japanese engineers will be dispatched to Indonesia and attend to the symposium.

And I expect more valuable data by deservation and better analysis will be shown.

I hope the good relationship and cooperation among erosion control engineers of both countries will be maintained in future. Thank you.

**5. GENERAL PROPOSAL FOR STUDY
IN FUTURE**

GENERAL PROPOSAL FOR STUDY IN FUTURE

1. Survey items in future

- 1) Rain fall
- 2) Time of occurrence of mud flow
- 3) Volume of mud flow
- 4) Velocity of mud flow
- 5) Material size of mud flow
- 6) Impact force of mud flow
- 7) River bed variation by mud flow
- 8) Temperature measurement of Lahar flow and Nuée Ardente

2. Extention of the term of the study

We, Japanese side and Indonesian side, intend to extend the term of the study one year.

3. Next symposium

The next symposium will be organized in Indonesia.

4. Report

Japanese side will make the report of 1977 fiscal year, which include the speeches and discussion in this symposium.

Indonesian side will make final report of the next symposium to be held in Indonesia.

6. APPENDIX

6-1. Delegates to Japan-Indonesia Symposium

INDONESIAN DELEGATION

SANADJI
Minister Counsellor, IEJ
ISMED B. SIREGAR
Industrial Attache, IEJ
RHOUSDY SOERIAATMADJA
First Secretary, IEJ
A. FAUZIE GANI
Attache
Ir. SURAJIL
Chairman of the Symposium
Chief, Sub-Directorate of Maintenance,
Directorate of Rivers
Ir. BAMBANG SUMANTRI
Project Manager, Mt. Merapi Project
in Yogyakarta
ISMANGUN SURYO
Volcanology Advisor to the Directorate
of Rivers
SUMITRO BRE
Supervision and Logistic Assistant,
Mt. Merapi Project

PWRI Public Works Research Institute
MC Ministry of Construction
MPWEP Ministry of Public Works and Electric Power
IEJ Indonesian Embassy in Japan
* Organizing Staff of the Symposium

JAPANESE DELEGATION

KAZUTO NAKAZAWA
Organizer of the Symposium
Director General, PWRI
MASASUKE WATARI
Chairman of the Symposium
Geotechnical Director, PWRI
DR. ARITSUNE TAKEI
Prof., Kyoto Univ.
DR. SETSUO OKUDA
Prof., Kyoto Univ.
HIROAKI TAMAMITSU
Director, International Cooperation
Division, MC
YOICHI TAKEUCHI
International Cooperation Division, MC
OSAMU MACHIDA
International Cooperation Division, MC
YOJI HABU
International Cooperation Division, MC
JIRO NAKAMURA
Director General, Erosion Control
Department, MC
USHIO DAIKUHARA
Director, Erosion Control Division, MC
KATSUTARO YANO
Erosion Control Division, MC
TADAHIRO MATSUSHITA
Erosion Control Division, MC
TAKEHISA SHITARA
Manager, Matsumoto Work Office, MC
MASAO TOSHIDA
Manager, Osumi Work Office, MC
TAKASHI SOTOKAWA
Director, Erosion Control Division,
Kagoshima Prefecture
TADAYOSHI OKUBO
Director, Planning Department, PWRI
KEISUKE TAKAGI
Director, Planning Division, PWRI
OSAMU TOYOSHIMA
Director, Akabane Branch, PWRI
YOSHIRO YOSHIOKA*
Director, Erosion Control Department,
PWRI
IWAO IZUMI*
Head, Erosion Control Division, PWRI

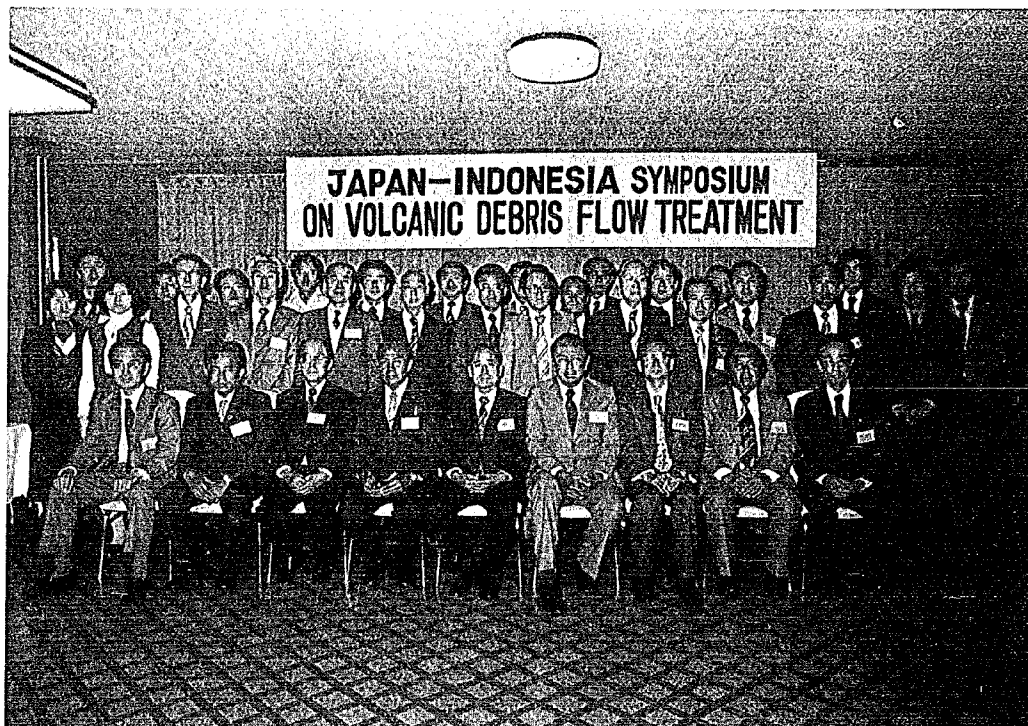
HIROSHI IKEYA*
Erosion Control Division, PWRI
OSAMU YAMAUCHI*
Erosion Control Division, PWRI
SOHEI ABE
Shinozaki Experimental Laboratory, PWRI

PARTICIPANT

AKITO NAKASUJI
Kokusai-Kogyo Co.
CHIYOJI IWASAKI
Yuzawa Work Office, MC
DENRO YASAKA
Japan International Cooperation Agency
HIROSHI SUZUKI
Sabo Technical Center Incorporated
Foundation
ICHIBEI MIYATA
Nippon-Koei Co.
ISAO TANI
Sabo Technical Center Incorporated
Foundation
KAZUMI NOBE
Kensetsu Gijutsu Co.
KEIJI NISHIMURA
Geographical Survey Institute, MC
KENICHI SASAKI
Disaster Prevention Division, MC
KOICHI HIRAO
Water Resource Development Public
Corporation
MASAICHI NAKAYAMA
Kokusai-Kogyo Co.
MASAYOSHI MATSUBAYASHI
The National River Conservation Sabo
Society
MICHIO TAKEDA
Japan International Cooperation Agency
MITSURU NAGAO
Japan International Cooperation Agency
SACHIO IWAMATSU
Division of Policy, MC
SEIYA IMANISHI
Oyo-Chishitsu Co.
SHINJI NAGAOKA
Asia-Kosoku Co.

SHOGO ISHIZUKA
Yazawa Work Office, MC
TAKAO HIROTA
Japan International Cooperation Agency
TAKASHI SUGIMOTO
Nippon-Koei Co.
TSUNEO MIZUHARA
Mie Prefectural Government
YASUO KIYONO
Ministry of Land Planning and Adjustment
YASUO TOMOMATSU
Disaster Prevention Division, MC.
YOSHIHISA HOSHINO
Geographical Survey Institute, MC
YOSHINORI TSURUYA
Slope Protection Division, MC
YOSHITAKE EGAWA
Tohoku Regional Construction Bureau, MC
YUICHI MARUYAMA
Asia-Kosoku Co.

6-2. Photographs of Symposium



Souvenir Picture for Symposium



Opening Address
Organizer of the Symposium Mr. K. NAKAZAWA
(Director General, P.W.R.I.)



Response
Chief of Indonesian Delegation Ir. SURAJIL
(Sub-Directorate of Maintenance,
Directorate of Rivers, M.P.W.E.P.)



Compliments
Embassy of Indonesia (in Tokyo)
Mr. SANADJI
(Minister Counsellor)



Compliments
Ministry of Construction
Mr. Jiro NAKAMURA
(Director General, Erosion Control Dep., M.C.)



Special lecture
Dr. Prof. Setsuo OKUDA
(KYOTO UNIV.)



Special lecture
Dr. Prof. Aritsune TAKEI
(KYOTO UNIV.)



Mr. Yoshiro YOSHIOKA
(P.W.R.I.)



Mr. SURYO (M.P.W.E.P.) and Chairman Group
(left to right, Mr. SURYO, Ir. SURAJIL,
Mr. IKEYA, Mr. WATARI).



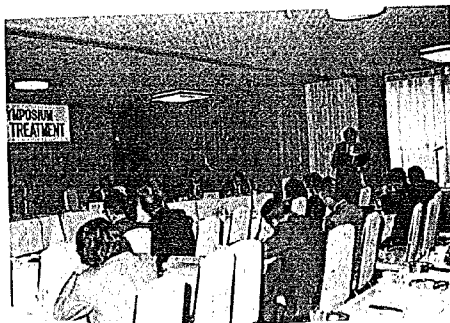
Mr. Osamu YAMAUCHI
(P.W.R.I.)



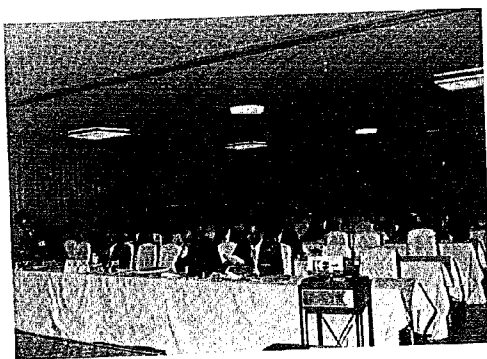
Ir. Bambang
(Manager of Mt. Merapi Project)



Mr. Tadahiro MATSUSHITA
(M.C.)



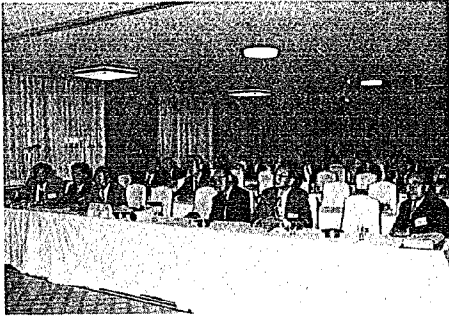
DISCUSSION



DISCUSSION



DISCUSSION



DISCUSSION



DISCUSSION



Closing address of Discussion
Chairman of the Symposium
Mr. Masasuke WATARI
(P.W.R.I.)



General Proposal for Study
(Ir. SURAJIL and Mr. YOSHIOKA)

6—3. How to Survey Mudflow

(JAPAN — INDONESIA JOINT STUDY)

1. OPERATION OF MUDFLOW CURRENT METER

- o Please read the instruction manual. (Appendix 1.)
- o The wire sensor shall be readjusted each time it is broken.

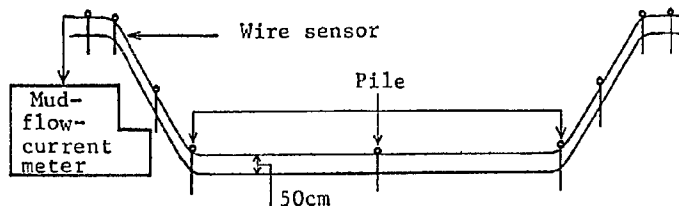


Fig. a How to install the Sensor

Note: If the pile is not driven sufficiently, it may fall at low water level flow. Otherwise, the sensor may be activated even without Lahar flow. If possible, it is better not to have the center pile.

The Method suggested by Mr. Ir. Bambang.

This method is evaluated a good method in preventing the damages to the wire by human causes. However, it has the disadvantages of difficulties in manufacturing and installing.

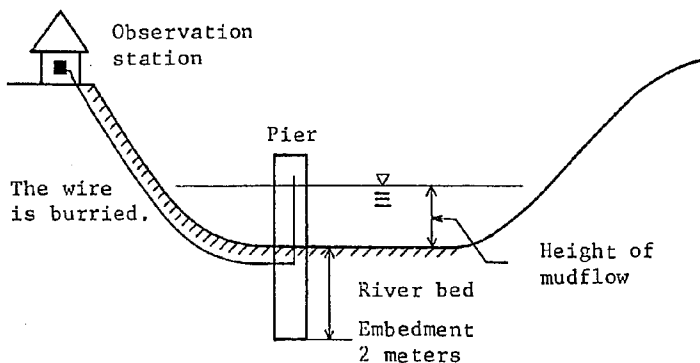


Fig. b

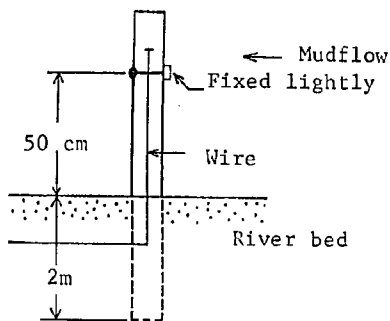


Fig. c

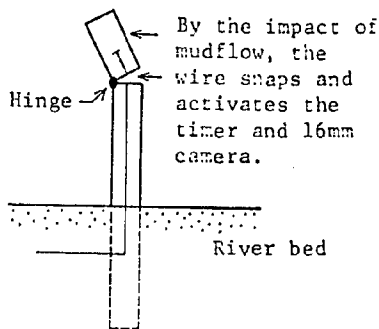


Fig. d

Pier Section

Size

Cross section : 20 cm square
Length : 3 m
Material : Concrete Mortar

2. METHOD OF INSTALLATION OF CINE CAMERA

The camera is to be installed after making peep window in the observation station so that the river channel is visible. It is considered better to adjust the zoom so that the full width of the river close to the fourth sensor counted from upstream is fully covered in the range of vision. However, the adjustment may be done according to the conditions prevail and after the zoom adjustment is made it shall be fixed with a mending tape or by some other method. When the object is too far, observation of mudflow becomes difficult due to mist and fog etc. See the instruction manual (Appendix 2) for the operation of camera.

For automatic start and stop of cinecamera, the camera is to be connected to the EXT OUT terminal of the Mudflow Current Meter. The method of connection is shown in the figure below. Remove the batteries from the camera.

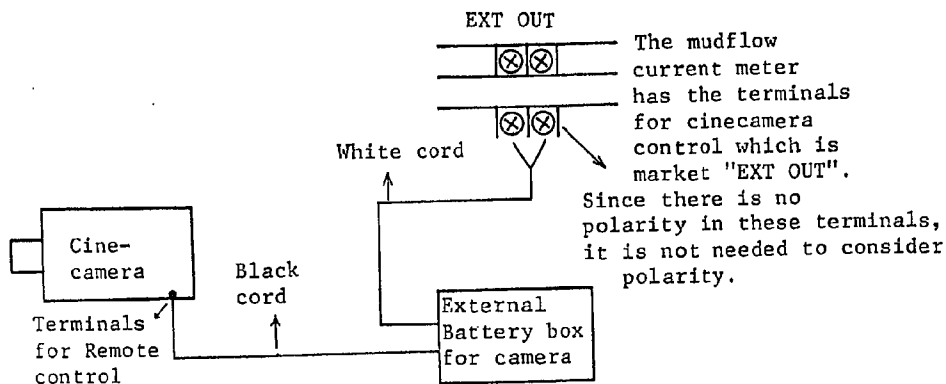


Fig. e

Turn the switches of camera and the external batteries for the camera to ON position. The camera starts automatically when the wire sensor No. 1 snaps and it stops automatically when the wire sensor No. 4 snaps.

3. ERECTION OF WATER LEVEL GAUGES

In order to observe the height of surge of mudflow, staff gauges are to be installed. Since a high resolving power can not be expected from the 16 mm films, it is better to mark the staff gauge with red and white paint at 20 cm alternative section. Further, in order to measure the velocity of surge of mudflow, install the above mentioned staff gauges at intervals of about 10 m.

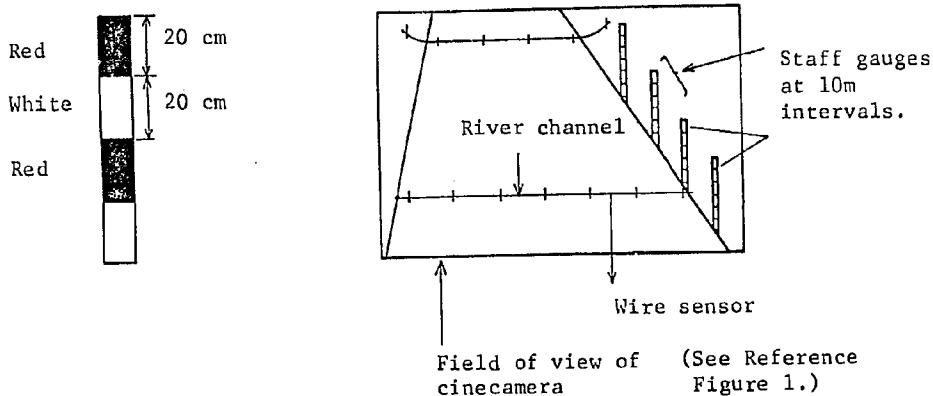


Fig. f

(See Reference Figure 1.)

4. INSTALLATION OF IMPACT PRESSUREMETER

In order to measure the impact force of the surge of mudflow, impact pressuremeters are to be installed on the main body of the Sabo dam or on its wings.

i) Method of Installation

Square holes (side length: 20 cm) are to be made on the main body or the wings of dam. The impact pressuremeter is to be set in this hole with bond, mortar etc., so that its front surface is in the same plane as the concrete surface of the dam and be free of irregularities.

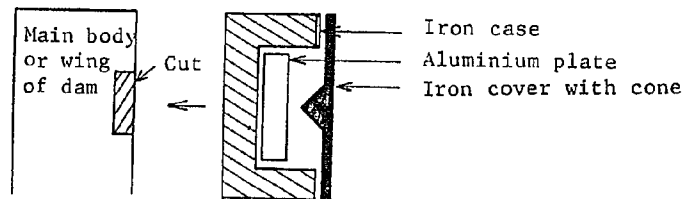


Fig. g

ii) Location of Installation

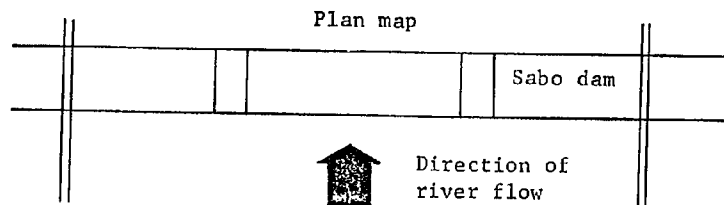
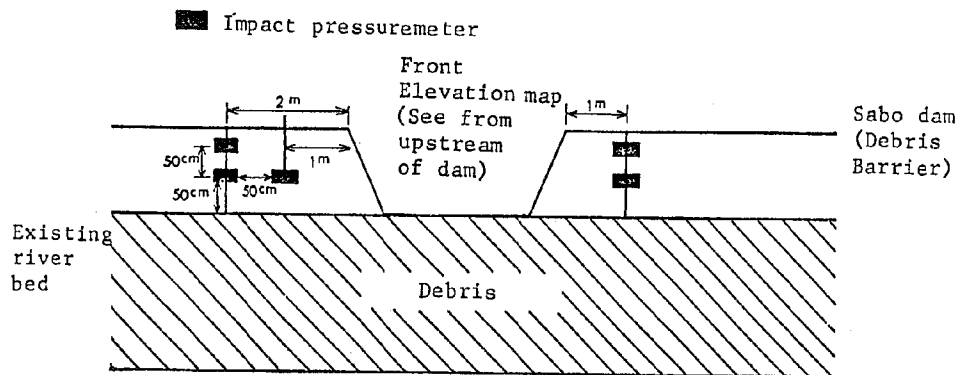


Fig. h

5. PRECAUTIONS REQUIRED IN OBSERVATIONS

5-1. Preparations for Observation are to be made in the following order.

- 1) After setting the wire sensor, check wheather there is anything out of order.
- 2) Load the film in to the camera.
- 3) A white sheet on which date and other comments are written is placed in front of the camera and it is filmed for about 10 seconds. (The camera can be operated by either shorting the EXT OUT terminals or by turning the test switch No. 1 to ON position.)
- 4) After all the inspections are over, by operating the test switches of the Mudflow Current Meter, test the camera whether it starts with No. 1 and stops with No. 4. This should not be done slowly as a large portion of the film will be consumed. The total exposing time of the film is about 3 minutes.

5-2. Inspection

The observation station should be inspected at least one a week. Inspections are to be done in the following order.

- 1) Start the inspection works after putting the switch of external battery box of the camera to OFF position. If this switch is not set to OFF position, sometimes the cinecamera may start accidently.
- 2) Exchange the batteries after switching off the Mudflow Current Meter.
- 3) Put on the main switch.
- 4) Press the reset button.
- 5) Put on the test switches No. 1 to No. 4 in order and check the movement of counter.
- 6) By setting the test switches in to their original position, set the counter to 0 by pressing the reset button.
- 7) Press the reset button.
- 8) After all the above operations are over, set the switch of external battery box of cinecamera to ON position.
- 9) Record the time of inspection and the condition at inspection in a field note. It is better to enter also the name of inspector.

5-3. When Mudflow Occurs

During the inspection, if it is found that the wire sensor is snapped (if the counter of the Mudflow Current Meter is moving), operation has to be done in the following order.

- 1) A white sheet on which the date of inspection and the cause of the occurrence of mudflow is filmed with the cinecamera.
- 2) Process the film as early as possible. After judging the height, velocity etc., of the mudflow, record these data in the investigation record sheets.
- 3) Take photographs (see the photographs in the "Guide to record observation data in the record sheets") of the condition of sedimentation in the river channel etc., and add these photographs to the investi-

gation record sheets. Fill all the items in the record sheets.

- 4) Set the Mudflow current meter for the next mudflow following the operation order stated in 5-1 and the instruction manuals for the camera and Mudflow current meter.

RECORD SHEET

Date and time of the occurrence of mudflow			Year		Month		Day		Hours		min.	
Time intervals the wire sensor snapped (sec.)			Wire sensor No. 1 ~ 2		2 ~ 3		3 ~ 4		Traveling time of mudflow to pass through as estimated by cinecamera			
			sec.		sec.		sec.		sec.			
Velocity (m/sec.)			m/s		m/s		m/s		m/s			
Height of surge observed from staff gauges			m				Maximum grain size		cm			
Impact mark	Impact pressure-meter No. No. 1 No. 6	Diameter of impact mark cm cm	No. No. 2 No. 7	diameter cm cm	No. No. 3 No. 8	diameter cm cm	No. No. 4 No. 9	diameter cm cm	No. No. 5 No. 10	diameter cm cm		
Condition of flow			Write the comments									

Records of Rainfall									
DATE	AM PM		AM PM		AM PM		AM PM		AM PM
1 hr.	mm	1 hr.	mm	1 hr.	mm	1 hr.	mm	1 hr.	mm
2		2		2		2		2	
3		3		3		3		3	
4		4		4		4		4	
5		5		5		5		5	
6		6		6		6		6	
7		7		7		7		7	
8		8		8		8		8	
9		9		9		9		9	
10		10		10		10		10	
11		11		11		11		11	
12		12		12		12		12	

Photographs

Append the photographs

Append the photographs

7. GUIDE TO RECORD OBSERVATION DATA IN THE FIELD NOTE

7-1. The Time of the Occurrence of Mudflow

Investigate accurately as far as possible by inquiring from the people in the area.

7-2. The Time Interval the Wire Sensor Snapped

The left one out of the three counters indicates the time interval of wire sensors No. 1 and No. 2. The unit of digital indicator is 0.1 second. Similarly, counter No. 2 represents the time difference between the snapping of wire sensors No. 2 and No. 3.

7-3. Traveling Time of Mudflow to Pass through as Estimated by Cinecamera

Calculate the traveling time of the frontage of mudflow to pass through the interval between two staff gauges (10 m intervals) by counting number of frames of the film exposed by the cinecamera during this time.

Example: When the filming speed is 24 frames/sec., if we assume that 50 frames were used to cover the passing of mudflow between two consecutive staff gauges, the time required would be;

$$50/24 = 2.08 \text{ seconds}$$

7-4. Velocity

- i) When the velocity is determined from the wire sensors, it is calculated from the distance (25 m) between the wire sensors.

Example: When the time of break between No. 1 to No. 2 is 5 seconds and that between No. 2 to No. 3 is 6 seconds, since the distance between these two sections is 25 m each, the velocity of mudflow between No. 1 to No. 3 is;

$$25/5 = 5 \text{ m/sec.}$$

and, the velocity of mudflow between No. 2 to No. 2 is;

$$25/6 = 4.16 \text{ m/sec.}$$

- ii) When the velocity of mudflow is determined from the cinecamera

If staff gauges are placed at 10 m intervals (if the staff gauge is carried away by the mudflow, consider the next nearest staff), the velocity is determined as

$$10 \text{ m}/2.08 \text{ sec. (See Para. 7-3)} = 4.80 \text{ m/sec.}$$

7-5. Height of Surge Measured by Staff Gauges

By projecting the cinecamera film on to a white paper, and by recording the projected image of staff gauges (each block distinguished by red and white represents a height of 20 cm), the height from the river bed could be estimated. When the water level is somewhere within the block the value is determined by eye measurement.

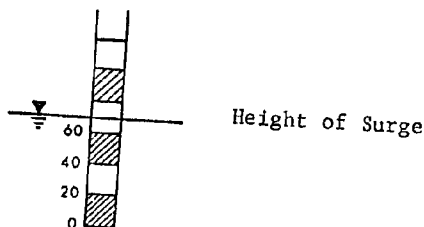


Fig. i

7-6. Maximum Grain Size

Record the maximum grain size of the debris material considered to have carried by the mudflow. Measure grain size as the average of longer diameter and shorter diameter.

7-7. Impact Pressure

Measure the size of impact wave up to millimeters from the mark left on the aluminium plate of the impact pressure meter.

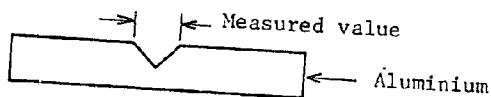


Fig. j

7-8. Condition of Flow

Record the condition of mudflow as how it is observed.

Example: A muddy viscous flow

Since the soil content is low in the surge it is more or less a mudflow.

7-9. Recording of Rainfall

Record the rainfall from the time it has started prior to the occurrence of mudflow until 10 hours after the occurrence of mudflow, as the hourly rainfall. From these materials on rainfall, it could be studied how and under what conditions of rainfall the mudflow occurs.

7-10. Photographs

It is better to take photographs of mudflow, before and after its occurrence and during its flow. (It is better to fix the location and direction of photographing.)