THE METHODS AND THEIR CONCEPT OF TORRENT CONTROL PLANNING IN JAPAN
—— THE PROBABILISTIC METHODS TO ESTIMATE THE MOVEMENT OF SEDIMENT YIELD CONNECTED WITH RAINFALLS ——

By
Sumiji KOBASHI, Aritsune TAKEI
Faculty of Agriculture, Kyoto University

SUMMARY

In this report, authors show a method to estimate the movement of soil mass caused by some rainfall in some torrent.

It is necessary to examine in three parts of torrent and its watershed for the exact analysis of moving process of soil mass.

The first part is the upper one of watershed that is the steep slope area formed unstable soil mass by breakout of slope failures. The volume of unstable soil mass is estimated with a probabilic method connected with the rainfall intensity.

The second part is the middle course of torrent in which the unstable soil mass is washed away by high flood water. It is showed results to estimate the sediment volume transported by the torrent runoff, that is based on two different concept, one is calculated with the concept that the sediment is transported by the tractive force on running water, the other is by the gravity and dispersive force.

The third part is the lower one of watershed, it is the alluvial fan. In this part, the soil mass is deposited. It is discussed a probabilistic method to estimate the deposit area (the hazard zone) with a random walk model.

key words Sediment yield, Probabilstic method, debris flow, random walk model

1. INTRODUCTION

It is first necessary to estimate the volume of soil mass removed in the watershed of a torrent in relation to conditions of rainfall, for the planning of erosion control.

The movement of soil mass in the watershed arises from failures of mountain slopes and debris-flows in small branch torrents by heavy rains in the upperpart of watershed. The gathered soil mass is flowed out by the flood-water along the middle course of torrent, then it is deposited on the alluvial fan.

The locality of human residence exists mainly in alluvial fans and disasters due to the movement of soil mass concentrate mostly in fans. So, for the investigation of disaster and its control, it is necessary to estimate

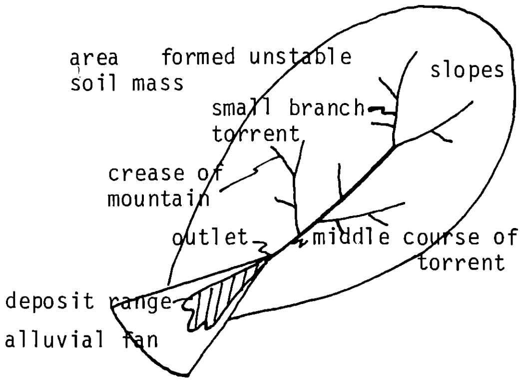

Figure 1 The movement of soil mass in the watershed of torrent

the deposit of soil mass in fans.

But, for the estimation of it, it is necessary not only to consider conditions of the fan, but also to estimate the volume of sediment yield and the flowing out process of it. They are decided with the volume of soil mass formed by slope failures and small debris-flows in the upperpart of the watershed, and with characteristics flowed out from the outlet of torrent.

In this report, the authors discuss three problems. these are as follows. (Figure 1)

The first problem is the estimation of unstable soil volume formed by slope failures and debris-flows in small torrent in the upperpart of torrent.

It is impossible to forecast exact places on which slope failures and debris-flows will break out. But it it is possible empirically to estimate the mean value and the standard deviation of the ratio of fail areas to stable areas in a watershed connected with a rain fall condition. And the sum of the volume can be estimated with a probabilistic method.

The second problem is the estimation of sediment volume trasported by the torrent runoff in the middle couse of torrent. It is necessary to discuss this problem from two different concepts. The one is analized with the concept that the sediment is transported by the tractive force of running water, when the rainfall intensity is moderate or the gradient of the torrent bed is gentle. The others is by the gravity and dispersive force (debris-flow), when the rainfall intensity is severe or the gradient is steep.

The third problem is the estimation of the deposit range on the alluvial fan. This is the most important problem, because it is the problem of the limitation of the hazard zone.

The deposit range is decided with the volume and attacking energy of soil mass, and micro topographical features of alluvial fan. Considering these two conditions, a probabilistic method should be used to estmate the deposit range (hazard zone) with a random walk model.

It is made an effort to synthesize three processes of the movement of soil mass above mentioned, and to estimate the probability of the disaster occurrence in connection with the return period of rainfall intensity and effects of torrent control planning. This report deals with torrents in the Rokko mountains as an illustration. This mountain is composed with the weathered granit. Unstable soil mass was abundantly formed by many slope failures and big debris-flows broke out repeatedly during heavy rains.
The large city of Kobe rests alluvial fans of the Rokko mountains. Big disasters occured repeatedly in the past.

The authors do not deal with the definite torrent but some assumed typcal model torrent is represented in the Rokko mountain, as it is thought to show more clearly the method using a simulation model.

2. THE ESTIMATION OF THE UNSTABLE SOIL VOLUME FORMED BY SLOPE FAILURES AND DEBRIS-FLOWS IN SMALL LATERAL TORRENTS.

In the Rokko mountain, places of break-out of failures occur mostly in slopes steeper than 30°, and concave positions(crease of mountain) that exist the uppermost part of stream.(Figure 2)

The number of creases in a watershed can be estimated with the Strahler formula of which the bifuration ratio is about 4.5 in the Rokko mountain, for example, there are about 91 creases in a watershed of 2nd order stream.

It is thought that the ratio of failure occurrence increases according to the intensity of the rainfall. Figure 3 shows the result in estimating the relation between the ratio and rainfall intensity.

The volume of soil formed by one failure is much variable, but this distribution shows a straight line on the log-normal curve paper.(Figure 4)

The slope failure in a crease accelerates frequently break-out of debris-flow in the 1st order stream connected with this crease. The ratio of the acceleration amounts to about 80%. This tendency of the acceleration is observed similarly on the relation between the 1st order stream and the 2nd order one.

By the occurrence of debris-flow in the stream, its bed is eroded severely. The distribution of the volume of eroded soil per 1m length of the stream bed shows a logarithum-normal along with the volume of soil formed by a failure.(Figure 5)

The sum of soil volume formed by failures and debris-flows does not flow out perfectly to the connected downward. The ratio of the amount flowed out to the sum of them is decided by the stream bed gradient and areas of watershed. It seems that the extent of watershed is propotioned to the quantity of rain water that is collected by the stream.

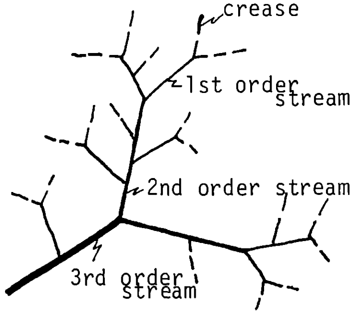

Figure 2 The stream order

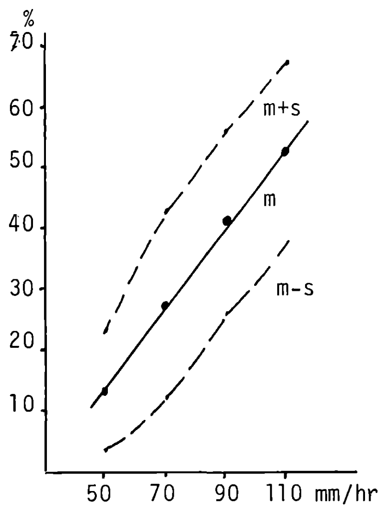

Figure 3 The relation between the ratio of failure in crease and the rainfall intensity.
m ; mean, s standard deviation.

Based on the productive process of unstable soil mass in the Rokko mountains, as mentioned above, it is thought that a simulating model estimates the relation between the sum of soil volume and the rainfall intensity. The flow chart of this simulating model is shown in Figure 6.

In this model, the area of 1km^2 produced unstable soil mass. This consists of steeper slopes than 30°, 1st order and 2nd order streams.

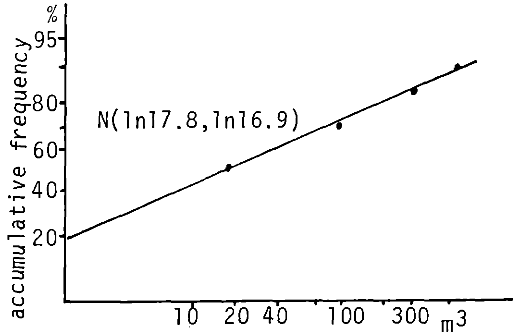

Figure 4 The volume of soil formed by one failure.
(logarithum-normal distribution)

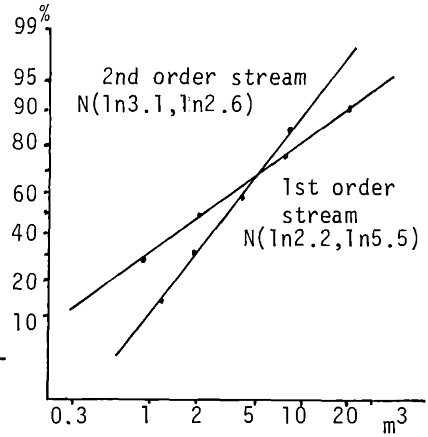

Figure 5 The volume of eroded soil per 1m length of the stream bed.(logarithum-normal distribution)

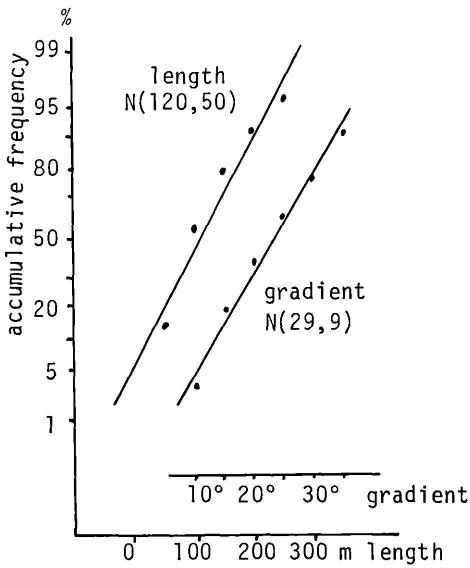

Figure 7 length and gradient of 1st order stream.
(normal distribution)

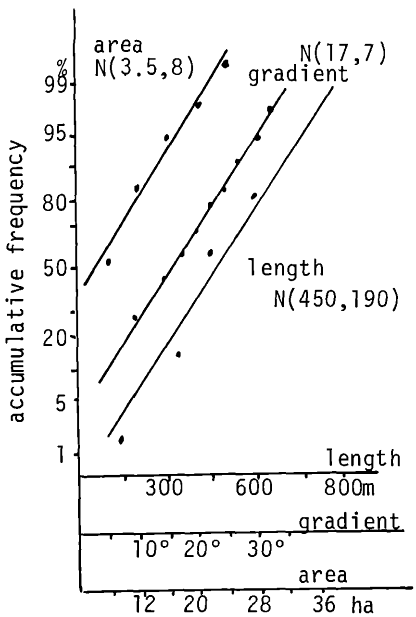

Figure 8 length,gradient and watershed area of 2nd order stream.
(normal distribution)

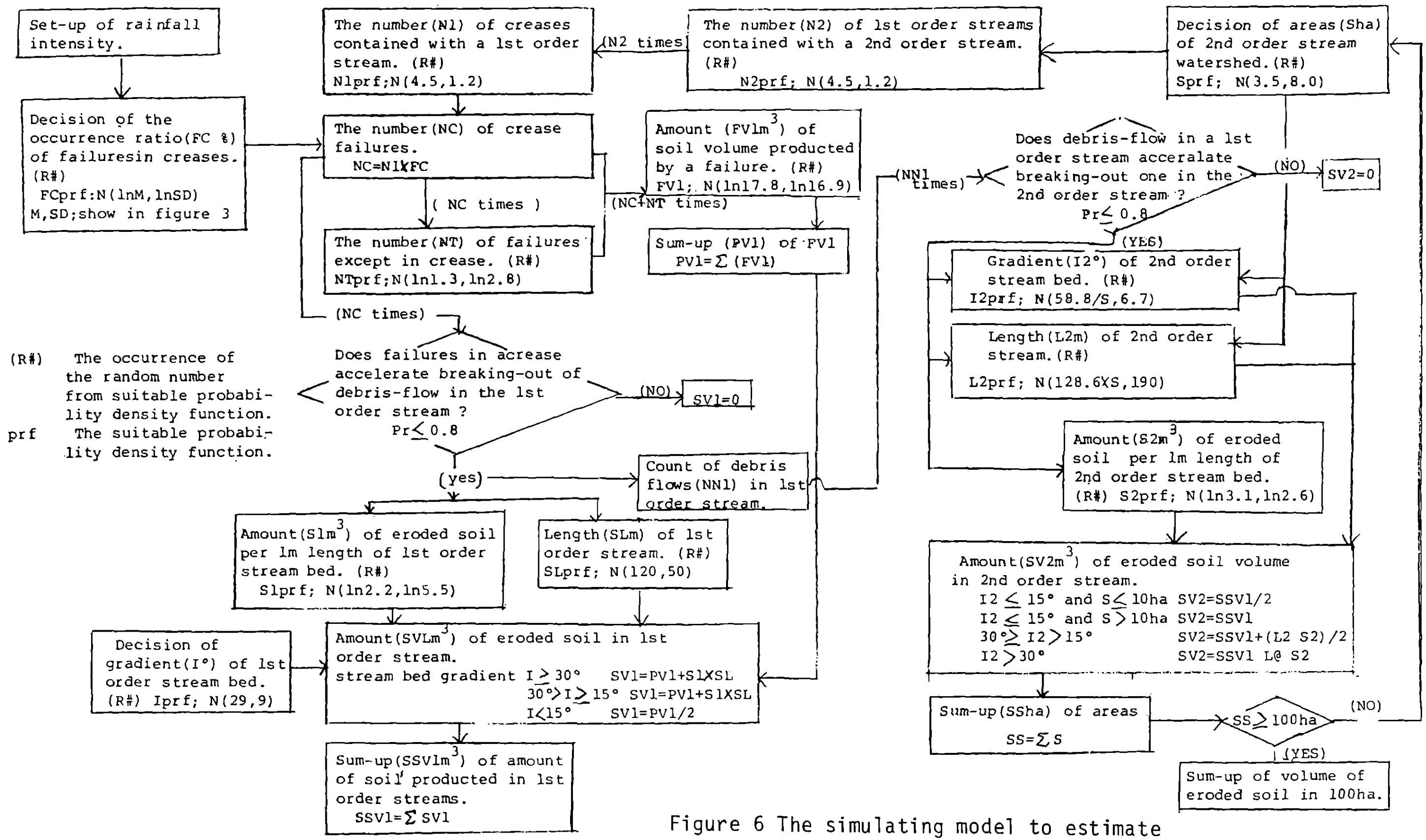

Figure 6 The simulating model to estimate the volume of unstable soil mass.

It is regarded as 2nd order stream as one unit.
The number of 1st order stream and creases of the mountain that are contained in the watershed of the 2nd order stream, the area, the gradient, the length and other many factors of 2nd order stream are much variable. but their distributions show a normal one.(Figure 7,8)
If the area that is formed unstable soil mass will aggregation of watershed of 2nd order streams, their factors can be decided by use of a random number introduced from the suitable probability density function(prf) of each one.
Figure 9 shows results of calculation with this model.
Calculations were repeated 500 times on each rainfall intensity to get frequency distributions. The frequency of the volume of unstable soil mass produced by some rainfall intensity showed a logarithmic normal distribution.

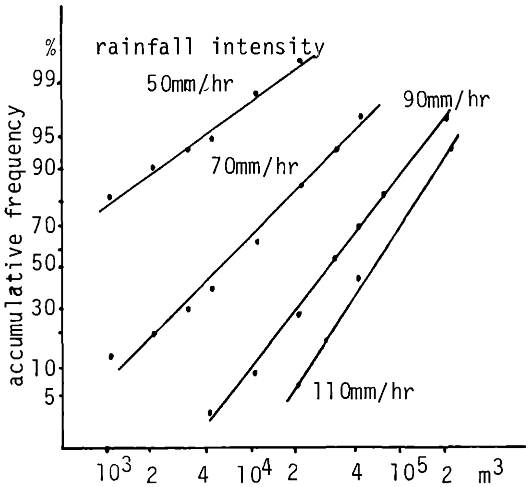

Figure 9 The result of calculation with the simulating model(Figure 6)

3. THE ESTIMATION OF THE VOLUME OF SEDIMENT YIELD RUNNING OUT FROM THE OUTLET OF THE TORRENT.

A part of unstable soil volume is transported from the outlet to the alluvial fan by the energy of the torrent flow.
The volume of sediment yield able to run out is regulated by the transporting force that is the tractive force(individual transportation), or the gravity force and the dispersive force(debris-flow).
on the ordinary rain condition, the sediment yield is transported by the tractive force that is controled with the hydraulical condition at the outlet of torrent. In the weathered granit regions, the Peter-Mayer-Müller formula is widely applicable to the estimation of the sediment yield volume. This formula is shown,

$$\frac{q_b}{\sqrt{(\sigma/\rho - 1)gd_m^3}} = 8\left[\frac{U_*}{(\sigma/\rho - 1)gd_m}(n_b/n)^{1.5} - 0.047\right]^{1.5} \qquad (1)$$

Several constants are given empirically, $n_b/n = 1$, $\sigma/\rho = 2.6$, $d_m = 4\text{cm}$, $n = 0.04$. Then the wide of the torrent outlet is B(m), the gradient of the torrent bed is θ, the run-off is Q, then the sediment yield(Q_b) is

$$Qb \quad 2534 \cdot B[0.0227(Q/B)^{0.6} I^{0.7} \quad 0.047]^{1.5} \qquad (2)$$

$I \quad \sin\theta$

It is necessary to find the estimation of Q. When the maximum rainfall per a hour(mm/hr) is given,it is assumed a hyetograph constituted with rainfalls per a hour that are reduced with a fixed rate(0.7) before and after, centering the hour of the maximum rainfall.(Figure 10)

And the hydrograph is introduced from this hyetograph,assuming as run-off ratio is 0.6.

On the heavy rain condition, the sediment yield transported with the shape of debris-flow. The rainfall condition for break-out of debris-flow is empirically made clear in the weathered granit regions.

It is defined a concept of effective rainfall(ER).

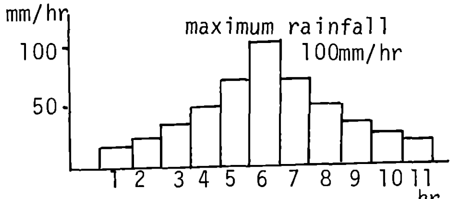

Figure 10 Assumed hyetograph

$$ER(t) = \alpha \cdot R(t) + \alpha^2 \cdot R(t-1) + \alpha^3 \cdot R(t-2) + \qquad (3)$$

ER(t) ; the effective rainfall(mm) at the t time, R(t) the rainfall intensity at the t time(mm/hr), α; constant(0.7).

When the ER value increased over 35mm, debris-flows have mostly broken out. As the shape of debris-flow, the volume of the sediment yield that is transported from the outlet of torrent is caluculated with the Takahashi formula,

$$Q_t = \frac{C_*}{C_* - [S + (1 - S)C_*]\, C_d} \cdot Q_o \qquad (4)$$

Where Q_t ; total discharge of water and soil. S ; degree of the satulation in the torrent bed. C_*; the bulk density of debris in the bed. C_d ; the bulk density of debris in the fluidized layer. Q_o the discharge of water supplied from upstream.

If several constants is assumed, C =0.6, C_d =0.4, S =1.0,

$$Q_t = 3 \cdot Q_o$$

The volume of sediment yield,

$$Q_b \quad Q_t \cdot C_d$$

Q_o is assumed the run-off during an hour at the time breaking out debris-flow.

Based on these concenpt, it is thought a simulating model as connected with the model (Chapter 2) estimated the unstable soil volume in the upper part of the watershed.(Figure 12)

In this calculation, the maximum rainfall intensity is given by the random number decided with the probability density function that is showed the occuring probability of the maximum value in a year relating to return period.(Figure 11)

And the wide of torrent outlet(B) is 20m, and its gradient is 4°.

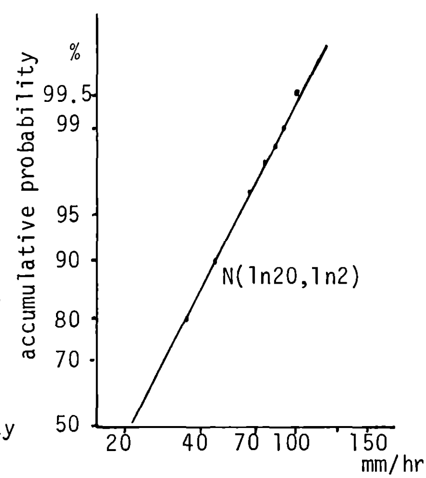

Figure 11 The occuring probability of the maximum rainfall intensity in a year.

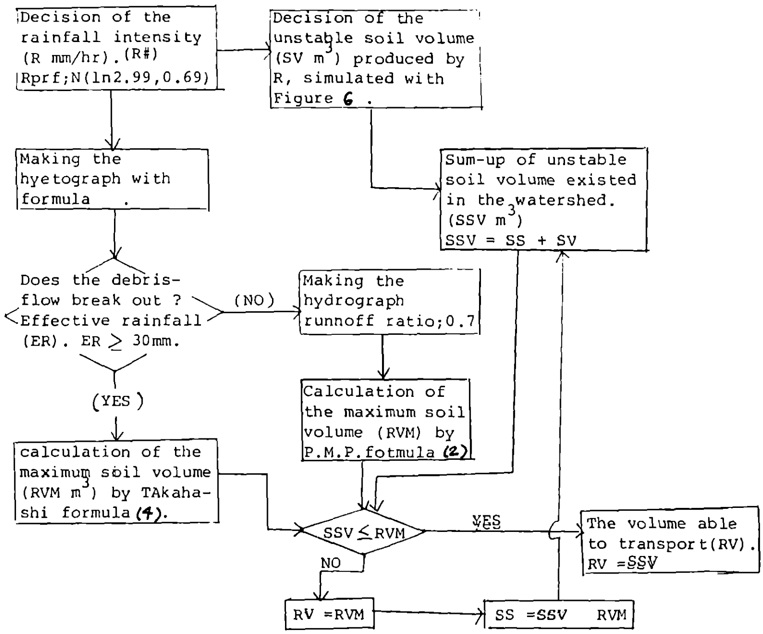

Figure 12 The simulating model to estimate the volume sediment yield transported from the outlet of torrent.

Calculations were repeated 500 times by the use of successive rainfall. This was decided randomly with the probability density function(Figure 11).

The result of the calculation is concluded Figure 13. This figure shows the occurrence probability of the volume of unstable soil formed in the upper part of watershed (SV) and the volume of sediment yield flowing out from the outlet of torrent(RV) by the maximum rainfall in a year, along with the volume of unstable soil that existed in the watershed (SSD). For example, when the occurrence probability is 5%, RV and SV is 50,000 m^3, and SSV is 220,000m^3.

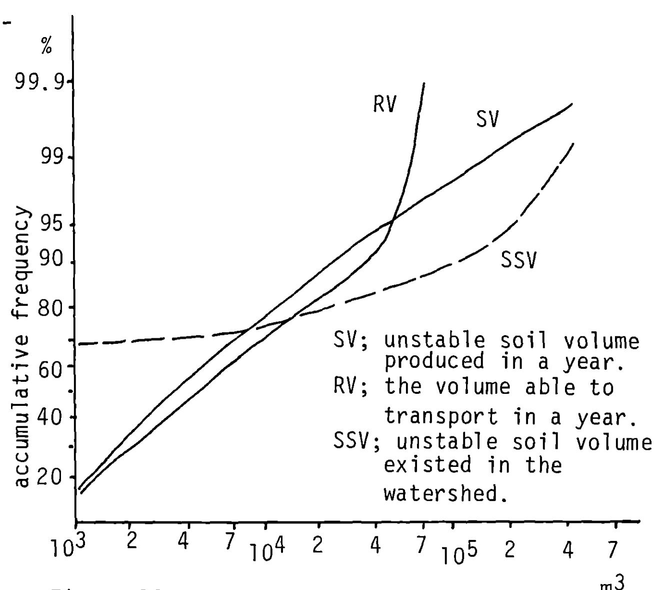

Figure 13 The result of calculation with simulating model of Figure 12

4. THE ESTIMATION OF DEPOSIT AREA ON THE ALLUVIAL FAN.

It is thought that the area of sedment yield deposit on the fan is decided with its volume and the flowing velocity, and the micro topographical features of the fan.

It is impossible to estimate theoretically its extent of two dimensions. So it is introduced a probabilistic method that is constituted with a random walk model based on the simple kinematics of material point system.

There are two types that the sediment yield flows out from outlet of torrent, individual transportation and debris-flow. But the type causing the big disaster is mostly debris-flow. So in this chapter, the only point discussed is debris-flow.

From the concept of Dr.Okuda, the movement of debris-flow,

$$\frac{dv}{dt} = A - \alpha k v^2 \qquad (5)$$

$$A \quad g(\sin\theta - \mu\cos\theta)$$

v ; velocity of debris-flow. α ; premium rate of drag coefficient with direction of debris-flow. k ; drag coefficient. g ; acceleration of gravity. θ ; gradient of stream bed. μ; coefficient of kinetic friction.

From formula (5), the relation between the distance(x) and velocity(v) is introduced.

$A \leq 0$ (reduce the speed),

$$x = \frac{1}{2\alpha k} \cdot \ln \frac{|A| + \alpha k v_0^2}{|A| + \alpha k v^2}$$

$A > 0$ (speed up),

$$x = \frac{1}{2\alpha k} \cdot \ln \frac{|A| - \alpha k v_0^2}{|A| - \alpha k v^2} \qquad (6)$$

v_0 initial velocity.

On the random walk model(Figure 15), the all extent of the fan is covered with the square meshes of the same size(usually this mesh size is 12.5 50m), and the elevation of the center point of each mesh is recorded from the topographical map.

The movement of random walk of debris-flow starts at the mesh of torrent outlet. The posibility of the progress exists to eight directions(Figure 14).

When the debris-flow advances to the next mesh, the direction that the fastest velocity will be supported will have the highest progressive probability.

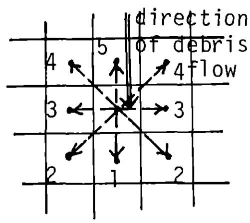

Figure 14
1; α= 1,2; α=2,
3; α= 5,4; α=10,
5; α=25

The velocity can be calculated by the formula(6). In this formula, k value is estimated 0.0005/m, and   is 0.085 in Yake mountain. This is the case that the debris-flow goes straight on. It is thought that as the debris-flow goes straight on, the drag force will be the minimum, and the greater drag force occurs as direction of debris-flow progress turns with the deeper bending angle. So it is assumed at follows

If the debris-flow goes straight on, α is 1. If the direction of it turns to 45° from the straight line, α is 2. If this degree is 90°, α is 5

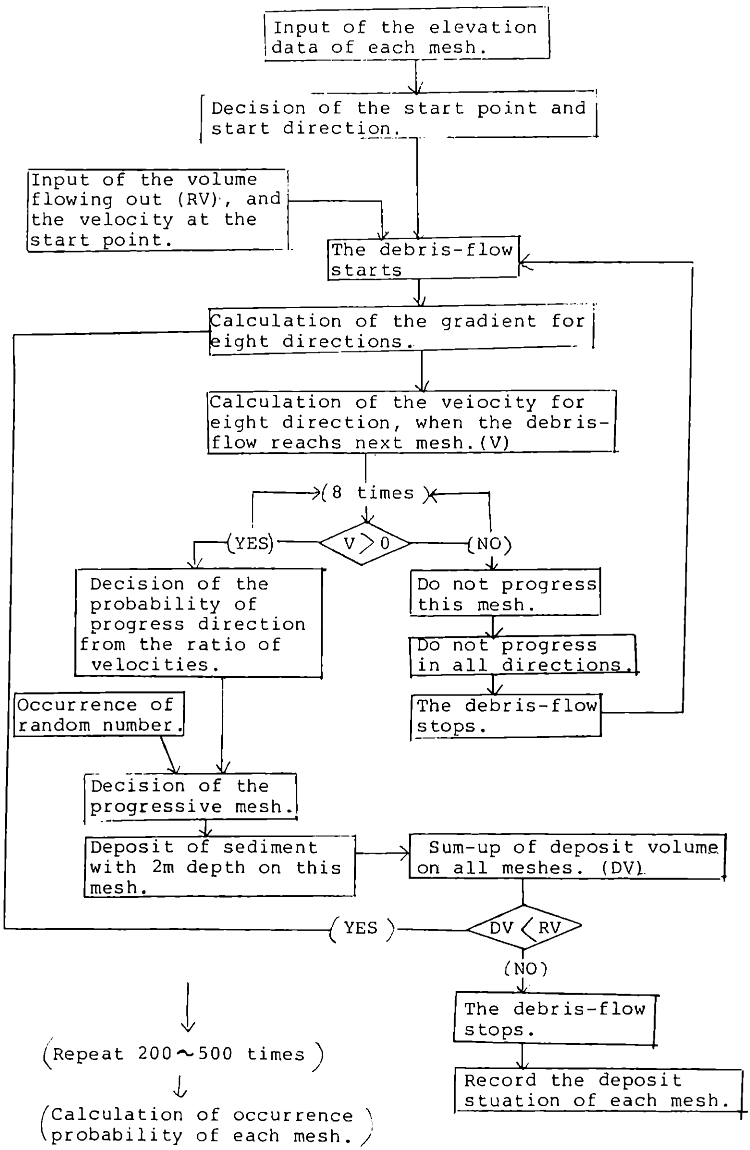

Figure 15 The flow chart of the random walk model.

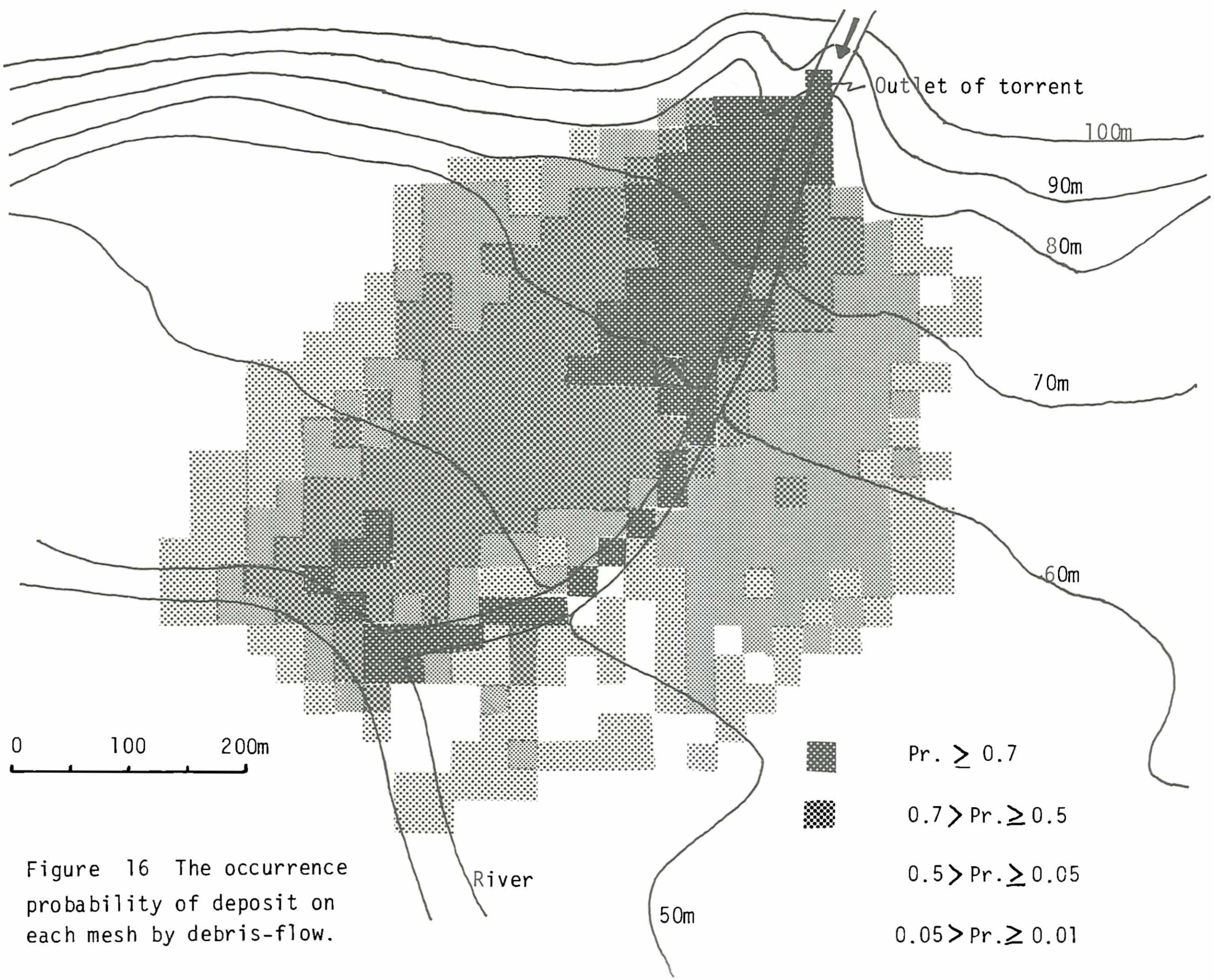

Figure 16 The occurrence probability of deposit on each mesh by debris-flow.

If this degree is 130°, α is 10. If this dgree is 180°, α is 25.
On meshes that the debris-flow passed, the sediment deposits with a prescribed depth(usually this depth is 2m).
The debris-flow stops when the volume of the deposit amounts to the same one running out from the outlet of the torrent, or the velocity of debris-flow decreases to 0 in all directions(in this case, if there is the remainder of sediment yield, it flows out from the outlet of torrent again.).
The Figure 16 shows the result of calculation with this model. This is showed by the occurrence probability of deposit on each mesh.
In this calculation, the volume of sediment running out is 50,000m^3. This agrees with the volume of 5% occurrence probability calculated in chapter 3(Figure 13), and the initial velocity of debris-flow is 10m/sec.
This method showed an estimation of the deposit area of the sediment yield that is caused by heavy rain. The effect of torrent control plans should be estimated by the reduction of the deposit area according to works of the control structure.

Zusammenfassung

In diesem Bericht zeigen die Autoren eine Methode um durch Regen bedingte Bewegungen von Bodenmaterial in einigen Wildbächen einzuschätzen (zu bestimmen).

Für eine exakte Analyse der Massenbewegungs-Prozesse (Vorgänge) ist es notwendig, Wildbäche und ihre Einzugsgebiete in drei Teilen zu prüfen.

Der erste Teil ist das obere Sammelgebiet, das sind die steilen Hänge mit unstabilen Bodenmassen, wo Hangbrüche auftreten. Das Volumen der unstabilen Bodenmassen wird eingeschätzt mit einer Wahrscheinlichkeitsmethode in Verbindung mit dem Niederschlag. Der zweite Teil ist der Mittellauf des Wildbaches durch welchen die unstabilen Massen bei Hochwasser hindurch geschleußt (transportiert) werden. Es werden zwei Methoden gezeigt, das durch den Wildbach abtransportierte Feststoffvolumen einzuschätzen, eine Methode beruht auf der Schleppkraft des fließenden Wassers, die andere beruht auf der Schwerkraft und der Dispersionskraft.

Der dritte Teil ist der untere Teil des Einzugsgebietes, der Schwemmkegel. In diesem Teil werden die Feststoffe abgelagert. Es wird eine Wahrscheinlichkeitsmethode diskutiert,

das Ablagerungsgebiet (Gefahrenzone) mit einem random walk-Modell abzuschätzen.

Schlüsselwörter: Feststofffracht, Wahrscheinlichkeitsmethode, Geschiebetrieb, Zufallsgangmodell.

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