1 Sediment Deposition in Sand-Pockets

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1. Introduction

A sand-pocket (遊砂地，砂溜工) is one of the sediment disaster prevention programs used in mountainous areas. The structure is basically a large area defined by dikes which intercepting and localizes the sediment deposit in an alluvial fan. The term “sand pocket “ is translated from the Indonesians phrase " Kantong Pasir" and it also called " Kantong lahar", because these structures have usually been built in volcanic areas, to cope with the volcanic material brought by lahar.

In Mt. Unzen, since the 1991 eruption, the sand-pocket has been utilized as an emergency measure to mitigate the damages in down reach areas. The case of sand-pockets in this area is interesting to be observes. Because, the volcano is still active and pyroclastic flow frequently flows down, the sediment control structure such as sand pockets and training dikes can be built only in down reach areas in order to reduce damage.

The sediment deposition processes in sand-pockets is an interesting matter to be observe, because they sometimes over flows or the dikes actually break.

2.Purpose of Study

When a stream flows onto an alluvial fans, flow directions change easily. Because this area does not have side walls like a river stream and/or sediment carried in the stream flow deposits gradually, the former stream channel is easily over flooded and the stream changes direction. A sand pocket is a typical structure in this area, that also has similar problems of the flow direction change.

The purpose of this study is to observe the characteristics of the flow direction change in a sand pocket in a laboratory. The distribution of sediment deposition, that is caused by the flow direction change is observed. A mathematical model is studied to simulate the sediment deposition processes. A two dimensional simulation model is also applied to simulate the distribution of sediment deposition.

3. Method of Experiment.

A flume; 10 cm wide, 20 cm deep and 250 cm long was connected to a deposition board, 90 cm wide and 110 cm long. The sediment material used for the experiment is d50= 0.25 mm, σ = 2.65 g/cm3. The sediment was set in the flume and water was supplied at the upstream end of the flume.

The slope gradient of the upstream flume was varied at the following degrees: 5, 8, 10 and 15 degrees. The downstream plane for deposition was changed 3 gradients, i.e. 1, 3 and 5 degrees. The water supply for this experiment varied as follows : 165 cm^3/sec, 330 cm^3/sec and 500cm^3/sec. The elevation of sediment deposition is measured by using “infra -red elevation measurement device” which is connected to a computer. Data were obtained automatically for position of X, Y, at 5 cm intervals, and Z, for elevation.

The processes of sediment deposition were recorded by a video camera vertically and the elevation of deposition was measured at two times, 45 and 90 seconds after the beginning of the experiments.

4. Results and Discussion

a Processes of Sediment Deposition

The first flow was straight and a hydraulic jump or a hydraulic bore were usually observed at the lower stream. Sediment was deposited behind the hydraulic bore. The hydraulic bore went upward along the stream until arriving at the outlet of the upper channel. Thareafter, the flow changed its direction.

b. Deviation of Stream Flow

The flow direction has a tendency to approach straight, when water supply is large and when the difference of slope gradient between upstream and downstream is small. The flow has a tendency to deviate more largely from the center, when the water discharge is small and when the difference of slope gradient between upstream and downstream is large.

Since the deviations of stream flow have obversed in unit time, the distribution plot of data is normal distribution. The result is shown in figure 1. The deviation of flow increases with the difference between upstream and downstream of slope gradient or when a water supply is smaller. In the second 45 seconds duration, however, the deviation is very scattered. This means that the flow direction is controlled by the relief of the former deposition in the first 45 seconds.
In other word initial relief of the alluvial fans influences the flow direction changing processes.

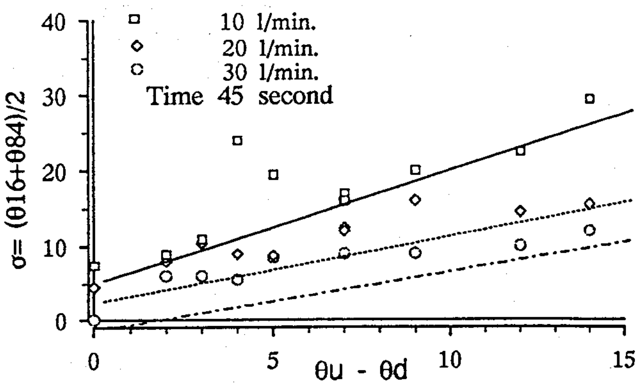

Fig. 1. Deviation of Direction Change

c. The Width of Stream

The width of the stream changed gradually, since the flow arrived on the deposition plane. In this area the stream flow is formed naturally and the width of stream was controlled by the water discharge from upstream. The width of stream at just the outlet of flume is approximately the same as the wide of flume and gradually becomes wider when flowing downstream.
However, when water discharge is small the stream created in the deposition plane is smaller than the width of the upstream flume. (Fig. 2)

Considering the "Regime Concept" for natural channel, width; $B= \alpha Q^{\beta}$, the distribution of the data on width is presented $\alpha= 3 - 7.8$ and exponent $\beta= 0.5$ in the middle reach.

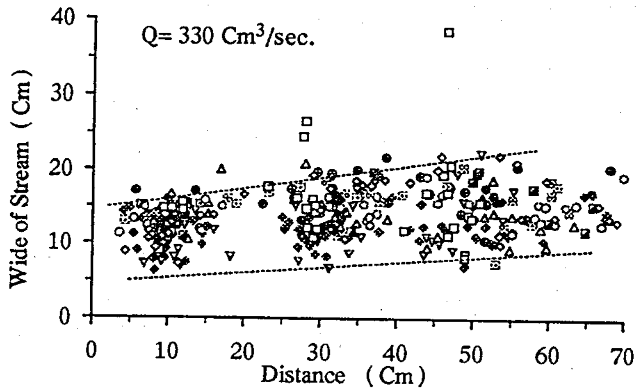

Fig. 2. The Wide of Stream Flow

d. Depositional Shape

A series of experiments shows wide variation of depositional shapes. The depositional shapes depend on not only the variation of flow direction but also sediment supply from upstream.
A bigger difference between upstream and downstream of slope gradient gives a smaller ratio of length and width of the deposition shape, because the sediment was spread more widely due to the large stream deviate. In other words, when the slope gradient difference is smaller, the ratio of length and width of deposition becomes larger and the deposition shape is narrower.

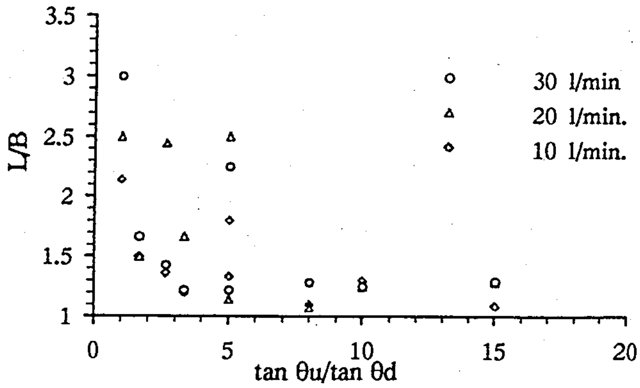

Fig. 3. Depositional Shape Characteristic

5. Numerical Simulation of Sediment Deposition Processes.

Natural sediment deposition processes vary greatly and complexes. The experiments in the laboratory were carried out to study the processes under specific conditions. A numerical model to simulate sediment deposition processes was applied under the same conditions as those in the laboratory. The comparison of those results gives more understanding to the transport of sediments and deposition processes.

5.1. One Dimensional Simulation

During the sediment flow influence in the deposition plane, the stream flow direction was changing. When the difference of the slope gradient between upstream and downstream is small and the water supply is large, the direction of stream flow approaches a straight flow. In this condition, the one dimensional simulation of sediment deposition can be applied.

The governing basic equations for this simulation are two conservation equations of fluid and sediment in open channels.

1. Mass conservation equations expressed:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \text{......................(1)}$$

where, A is cross-sectional area and Q is flow discharge ; t is time and x distance.

Since the flow was calculated at each point and times, the equation becomes :

$$\frac{\partial z_i}{\partial t_i}+\frac{1}{(1-\lambda)\cdot B_i}\cdot\frac{\partial(q_{Bi}\cdot B_i)}{\partial x}=0 \text{...........(2)}$$

q_{bi} is water discharge per unit width and B_i ; Z_i are parameters of water depth and width of stream at each point and time of calculation ; λ is porosity of sediment.

In this case it is assumed that in this process there is no water inflow or outflow from the stream and the stream flow is uniform between two calculation point sequences.

2. During the processing the direction of flow changes and it is difficult to use the momentum conservation. Accordingly the conservation of energy can be applied. The conservation of energy is.

$$\frac{1}{g}\frac{\partial v}{\partial t}+\frac{\partial}{\partial x}\left(\frac{v^2}{2g}+h+z_b\right)=i_e \text{........(3)}$$

where an energy gradient $i_e=\frac{\tau}{\varrho g h}$.........(4)

The sediment processes are calculated based upon the difference of sediment discharge per unit time, between two observation points in sequences.

$$\Delta zi=\frac{q_{b(i)}-q_{b(i+1)}}{B_i(1-\lambda)\Delta x} \text{............(5)}$$

if Δz > 0 sediment deposit
< 0 erosion
= 0 stable

Since the grain of sediment was uniform, the sediment transport equation is :
(Mizuyama , 1977)

$$\frac{q_B}{\sqrt{g\left(\frac{\sigma}{\varrho}-1\right).d^3}}=12.\tau_*^{3/2}.\left(1-0.85\frac{\tau_{*c}}{\tau_*}\right).\left(1-0.92\sqrt{\frac{\tau_{*c}}{\tau_*}}\right) \text{.........(6)}$$

The result of calculation and experiment is as follows:

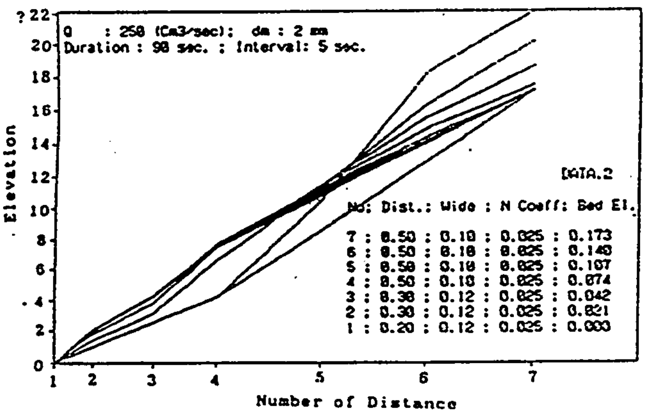

Fig. 4. One Dimensional Simulation Calculation.

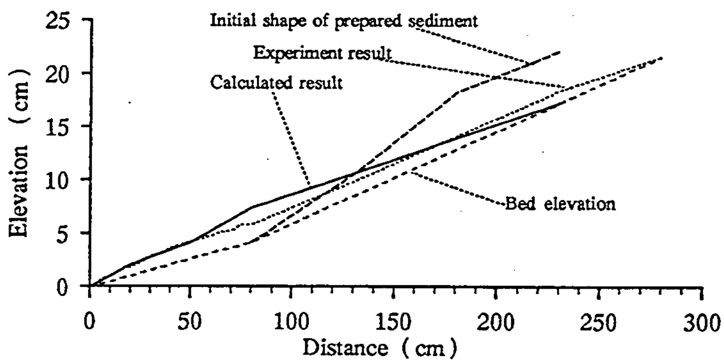

Fig. 5. Comparison of Experiment and Calculated Result

5.2. Two Dimensional Simulation

The studies of sediment deposition in the laboratory allow us to understand the processes of sediment deposition. The flow direction change plays an important part regarding the distribution of sediment deposit. Numerical simulation by one dimension makes clear the processes by time to time, but the pattern of spreading sediment deposition in plane view does not appear. Numerical simulation of two dimensions simulates the distribution of sediment.

The two dimensional debris flow simulation models developed by K. Matsumura, (1993). There are three basic equations which developed for the simulations that are :

1. Equation of motion in x and y direction

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}(\beta.u_m M)+\frac{\partial}{\partial y}(\beta.v_m M)=-gh\frac{\partial H}{\partial x}-\frac{\tau_{bx}}{\varrho}\text{......(7)}$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}(\beta.u_m N)+\frac{\partial}{\partial y}(\beta.v_m N)=-gh\frac{\partial H}{\partial y}-\frac{\tau_{bx}}{\varrho}\text{........(8)}$$

in which :
M : momentum in x direction ($M=h.u_m$)
N : Momentum in y direction ($N=h.v_m$)
u_m ; v_m are velocity in x and y ; h : water depth ; H : elevation ; g: gravitation ; ß : Momentum coefficient and τ_{bx} ; τ_{by} : shear stress in x and y direction.

2. Equation of continuity

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0\text{..............(9)}$$

Since the front of debris flow was deposited on the apex of alluvial fans, it would be eroded by following flows and spread downward.

Mizuyama at al. develops the equation of continuity of sediment and water separately.

a. Equation of continuity for water in debris flow

$$\frac{\partial}{\partial t}\left((1-c_d)\cdot h\right)+(1-c_*)\cdot\frac{\partial z}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=0\text{.........(10)}$$

b. Equation of continuity for debris

$$\frac{\partial(c_d.h)}{\partial t}+c_*\cdot\frac{\partial z}{\partial t}+\frac{\partial q_{Bx}}{\partial x}+\frac{\partial q_{By}}{\partial y}=0\text{.......................(11)}$$

The sediment concentration is calculated, according to a type of flow using the equations developed by Tahahashi (debris flow...12) and Mizuyama (hyper-concentrated flow...13), which judge according to slope gradients. The bedload transport on gentle slopes is calculated by using the brown's formula.(...14)

$$Cn=\frac{\varrho\tan\theta}{(\sigma-\varrho)(\tan\phi-\tan\theta)}\text{.............(12)}$$

$$Cn=\frac{5.5\tan^2\theta}{1-5.5\tan^2\theta}\text{..........................(13)}$$

$$q_b=10\tau_*^2\cdot u_*\cdot d\text{..............................(14)}$$

The calculation results of elevation gave the configuration of deposition three dimensionally.

```
*** calculation condition (at upper boundary)***
     cm  =   1.000000000000000E-001
     qq  =    .003330         uu  =     .327899          hu  =     .010156

*** sediment depth at each mesh ***                                          calculation
.......hasilnya adalah ........          time passed :    0h   0m 45s
 ******************                                                        t  = (15)+30 second
 ******+34********                                                         Cd  = 10 %
 *****+2333+*******
 *****+33332+******
 ****+2333221+*****
 ****122332211+****
 ****122332211+****
 ***1122322211+****
 ****112222111+****
 ****112221111+****
 *****111111+******
 *****11111+*******
 ******************
 ******************
 ******************
 ******************
 ******************
sediment volume       (with void)=   .484118146E-02   (m3)
sedi. vol. supplied (with void)=   .499500000E-02   (m3)
sedi. vol. suspended              =   .983472992E-04   (m3)
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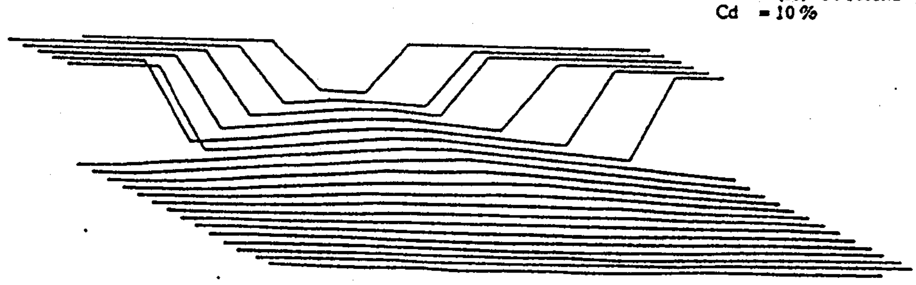

Fig. 7. The result of calculation.

6. Reference:

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