

Measurement of debris flow and sediment-laden flow using a conveyor-belt flume in a laboratory

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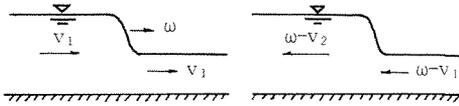
ABSTRACT Though a bore is a nonsteady flow, it can be treated as a steady flow in a coordinate system which moves at the same speed as the bore. To make a steady bore in the laboratory, a conveyor-belt type of flume with a movable bed was constructed. By setting the belt speed to that of the bore front, a static debris bore was obtained. In addition flow of zero mean velocity was obtained by setting the belt speed to that of the mean flow velocity for a selected slope. In this way detailed observations of grain behaviour over long periods were possible with improved measurement accuracy. Experiments on debris flow and sediment-laden flow were undertaken incorporating measurements of grain concentration, velocity distribution and grain trajectories.

Mesure de l'écoulement des débris flottants et de l'écoulement chargé en sédiments au moyen d'un canal à transporteur à courroie au laboratoire

RESUME La mascaret correspond essentiellement à un écoulement non-stationnaire, cependant il peut être traité comme un écoulement stationnaire lorsqu'il se trouve dans un système de coordonnées qui se déplace à la même vitesse que celle du mascaret. Afin d'obtenir un mascaret stationnaire dans un laboratoire, on a construit un type de canal à transporteur à courroie muni d'un bâti mobile. En égalisant la vitesse de la courroie à celle du front du mascaret, on a pu obtenir dans le canal un mascaret de débris stationnaire. Un écoulement de vitesse moyenne zéro est également réalisable en égalisant la vitesse de courroie à la vitesse moyenne de l'écoulement avec une pente d'un talus arbitrairement choisie. Dans ces écoulements, on peut aboutir à des observations détaillées de comportement des grains sur de longue période en améliorant l'exactitude. A la suite des expériences sur l'écoulement des débris flottants et sur l'écoulement chargé de sédiment dans le canal, et en mesurant la concentration en sédiments, la distribution des vitesses ainsi que les trajectoires des grains, nous avons obtenu quelques renseignements intéressants.

INTRODUCTION

In most cases, debris flow tends to form a bore with a swollen front. A bore is a nonsteady flow, but by considering it with reference to a coordinate system moving at the same speed as the bore (Fig. 1), it can be treated as a steady flow. In



(a) fixed system (b) moving system

Fig. 1 The coordinate system.

the laboratory, however, it is difficult to move instruments at the same speed as a bore, and even if it were possible to do this, the high velocity of the bore would only allow a short period of observation. However by moving the bed upstream it is possible to keep the bore static, thereby making it possible to observe it for a longer time. Therefore a conveyor-belt type of flume was constructed to study the behaviour of bores.

THE CONVEYOR-BELT FLUME

The experimental flume, made of acrylite on both sides, measured 2 m long x 10 cm wide x 20 cm high with the conveyor-belt in close contact with the bed. The layout of the equipment is shown in Fig. 2. The belt had a variable speed within the range 0-2 m s⁻¹ while its slope could be varied from 0 to 0.5. A bore

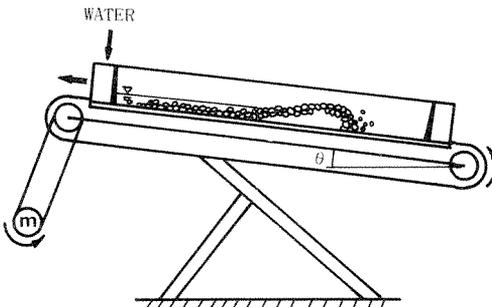


Fig. 2 Experimental apparatus.

was generated by introducing water and grains on to the moving belt at the upstream end of the belt. Then by suitably adjusting the belt speed, bed slope and water supply, the average position of the front of the bore could be kept stationary. Therefore it could be regarded as a static bore, even though over a certain period the front of the bore fluctuated slightly upstream and downstream because of the unevenness of the belt (seamed position) and flow turbulence. As the average shape did not change in time, the discharge and mean velocity became zero throughout the

channel.

A circular flume with a moving bed is often adopted, but the slope of this type of channel cannot be varied. The conveyor-belt type of flume has the following advantages over normal flumes:

(a) Flow with a selected velocity can be set up for a selected slope. For instance, flow of zero mean velocity, flow with zero velocity at the surface, and uniform flow with reversed slope are easily obtainable.

(b) In the case where grains are introduced into the flow, it is possible to make detailed observations of grain behaviour over a long period. Measurement accuracy may be improved by generating the flow which has a velocity the same as that of the grain. For example, even if the measured values of flow velocity, velocity of grain A and velocity of grain B in a normal flume have been obtained, respectively, as $V_m = 100 \text{ cm s}^{-1}$, $V_A = 102 \text{ cm s}^{-1}$ and $V_B = 98 \text{ cm s}^{-1}$, it is too hasty to conclude that $V_A > V_m > V_B$ when taking into consideration the accuracy of the measurements and fluctuations in the data. However, when the flow, with velocity $V_m = 0$, is established in the conveyor-belt flume and measurements then taken, grain A moves downstream at velocity $V_A = 2 \text{ cm s}^{-1}$ while grain B moves upstream at velocity $V_B = 2 \text{ cm s}^{-1}$. It is not difficult to measure these differences precisely.

RESULTS AND DISCUSSION

Behaviour of grains in the flow

The behaviour of gravel, glass balls and steel balls introduced into the water flow of the conveyor-belt flume with a steady bore, was recorded by a cine camera and analysed. The characteristics of the grains used were:

| <i>material</i> | <i>diameter (mm)</i> | <i>density (g cm⁻³)</i> |
|-----------------|----------------------|------------------------------------|
| gravel | 0.83-13.5 | 2.65 |
| glass | 1.1-12.5 | 2.54 |
| steel | 1.6-11.2 | 7.86 |

The grains usually saltated along the bed, and since water flowed in a upstream direction near the bed and downstream near the surface, the grains assumed an elliptic trajectory as shown in Fig. 3. The ratio of average grain speed to belt speed was plotted against grain size (Fig. 4). The ball speed is seen to increase with an increase in grain size, which is to be expected from the law of gravity, as a ball would roll down the bed slope even if there were no flow.

However, while gravels with a certain range of sizes travelled downstream, i.e. faster than the mean flow velocity, gravels with grain size larger or smaller than this range moved upstream, i.e. more slowly than the mean flow velocity, resulting in a concentration of grains of certain sizes at the bore front. The relationship between velocity and grain size was theoretically proven by a simulation conducted by Hirano *et al.* (1978). The sorting of grains was seen to occur in the direction of flow when grains of different size were put into the flow.

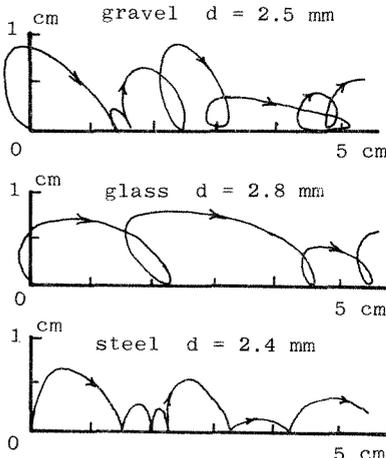


Fig. 3 Trajectories of grains in the flow.

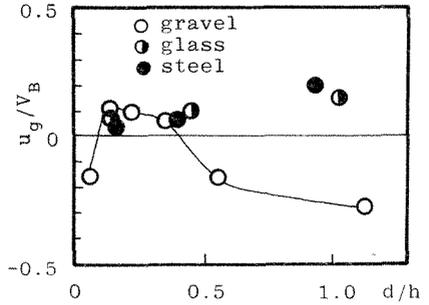


Fig. 4 Velocity of grain (u_g , average velocity of grain; V_B , belt speed; d , grain diameter; and h , flow depth).

The velocity distribution of debris flow

Mesalight grains of 8 mm diameter and specific gravity of 1.55 were used to examine debris flow. The velocity of the grains was monitored by a motor-driven camera. The results are shown in Fig. 5. The upper grains were seen to move downstream, while the lower ones moved upstream. The velocity distribution in a fixed coordinate system was obtained by adding the belt speed to the grain velocity (Fig. 6). Although the velocity distribution in

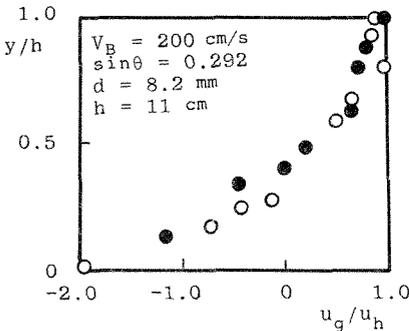


Fig. 5 Velocity distribution of debris flow (u_h , velocity at the surface; and y , distance from the bed).

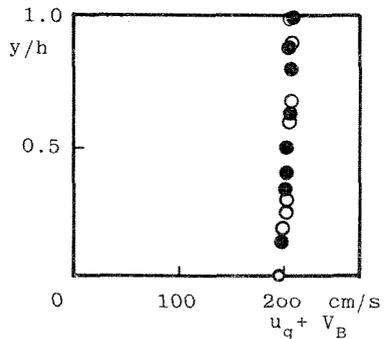


Fig. 6 Velocity distribution in a fixed coordinate system.

this system seems uniform and looks like Bingham flow, it is apparent from Fig. 5 that it is not Bingham flow but shear flow. As demonstrated above, one of the advantages of the conveyor-belt flume is that it permits the detection of very slight velocity differences which cannot be measured in a normal flume.

Figure 5 also shows that the grains slipped on the bed surface. Bagnold (1954) performed experiments of grain dispersion in an annulus with a rotating outer boundary, but failed to take into account "grain slip" at the boundaries. However, in view of the probable grain slip, reconsideration of his results may be necessary.

Concentration of debris flow

Samples were collected by inserting a cylinder into the debris flow as shown in Fig. 7. The belt was brought to a halt as soon as the cylinder had fully penetrated the flow. The concentration was obtained by measuring the height of debris flow, H , and grain depth in the cylinder, D , using the expression:

$$C_m/C_* = D/H \tag{1}$$

where C_m is the mean concentration of debris flow and C_* is the maximum possible concentration. The values obtained are plotted in Fig. 8. This shows that the mean concentration hardly varied with regard to the slope of the bed and the belt speed.

In order to determine the distribution of the grains, a photograph was taken, from which the number of grains in contact with the side wall were counted.

A small area of length ℓ and height h was then marked off on the side walls as shown in Fig. 9. Assuming that the number of grains in contact with this area is n and the number of grains existing in a cube of $\ell \times \ell \times h$ is N , N is considered to be proportional to n^2 and thus the concentration in the cube, C , is given by the equation

$$C = \frac{N \pi d^3 / 6}{\ell^2 \Delta h} \propto \frac{n^2 d^3}{\ell^2 \Delta h} \tag{2}$$

where d is the grain diameter. When the grains are uniform in size,

$$C/C_o = (n/n_o)^2 \tag{3}$$

where C_o and n_o are the concentration and the number of grains at the standard level respectively. Figure 10 shows the distribution of grain concentration obtained by equation (3) when $\ell = 10$ cm and $h = 1$ cm. The concentration seems to be even

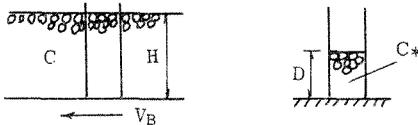


Fig. 7 Measurement of concentration.

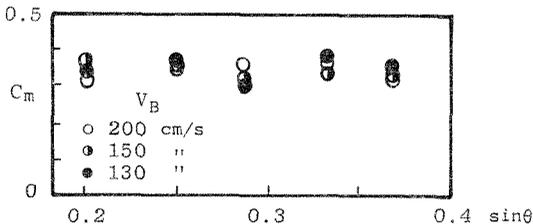


Fig. 8 Mean concentration of debris flow.

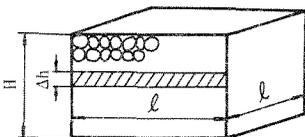


Fig. 9 Definition sketch.

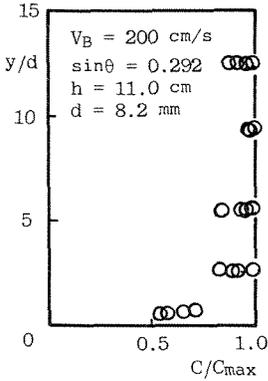


Fig. 10 Distribution of concentration.

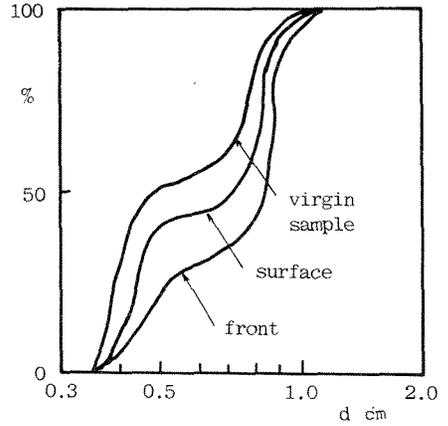


Fig. 11 Grain size distribution in debris flow.

except on the bed.

Contrary to the case of suspended load, the concentration near the bed is lower than that near the surface.

Sorting of grains at the debris front

Concentrations of large grains have been frequently observed at the front of rocky debris flow. Figure 11 shows the initial grain distribution, the distribution on the surface and at the front of the debris flow. From this figure it can be seen that there is a concentration of large grains at the front of the debris flow. Furthermore, the reverse grading is seen to occur, and this is a well known phenomenon in shear flow sedimentation.

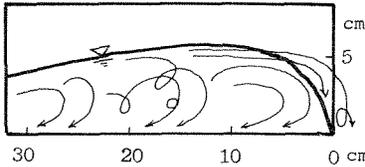


Fig. 12 Trajectory of grains at the front of the debris flow.

The trajectories of grains obtained by VTR are shown in Fig. 12. Because of the existing velocity distribution as shown in Fig. 5, the upper grains, arriving at the front, fall to the bed and are carried upstream in the flow near the bed, thus recirculating in the debris flow. Large grains are more resistant to being caught in the flow than small ones, and tend to stay at the front, thus explaining the occurrence of concentrations of large grains at the front.

REFERENCES

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 Hirano, M., Iwamoto, M. & Saruwatari, H. (1978) Some experimental studies of flow in flume with belt-conveyor bed. *Proc. 22th Japanese Conf. on Hydraulics*, 283-289.