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Techniques for Sediment Discharge Measurement in Laboratories

By Kenji SAWAI

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Abstract

New measurement techniques for sediment discharge have been devised, employing both direct and indirect methods. In the direct method, two devices were made. The first one had a fixed inclined 0.3 mm mesh screen, pump and baskets driven by a belt. Because of the choke of the sieve etc., the applicability of this system was limited in the range of $Q<20$ l/s, $Q_s=0.2-1.0$ kg/min and $d=0.4-2.0$ mm. The second device consisted of a trommel and a tipping bucket hung to a load cell. This device has been found to work well for sand and small gravel up to a flow rate of 40 l/s.

In the indirect method, the author tested the idea of utilizing a microphone confined in a pipe. Using this method, the sound generated by the collision of the gravel particles was clearly detected. When the pipe is set on the bed surface, the statistical property of the collision depends on the flow condition. However, when the pipe is attached to a board which is set at an appropriate height at a step-down such as the downstream end of a flume, it no longer strongly depends on the flow condition. In that conformation, however, it is apt to be broken by the impact of gravel.

1. Introduction

It is important to know the sediment discharge passing through the river course to enable the planning of river control. Recently, the Ministry of Construction reviewed the present methods taken in the field and laboratories to measure sediment discharge and proposed some new techniques both direct and indirect. Although much effort has been made, it is still difficult to measure sediment discharge except under relatively mild conditions[1)-4)].

Methods of sediment discharge measurement may be classified into two major types. The first is to directly measure the volume or weight of sediment, while indirect methods measure other parameters related to sediment discharge such as sounds or images.

In order to measure the volume or weight of sediment directly, it is usually trapped somewhere for an appropriate time. When sediment is trapped in a basin or pit, it is relatively easy to measure its volume or weight. However, if the basin is not large enough, sediment tends to escape even before it is filled. Furthermore, as the basin or pit must be set before measurement, it is difficult to alter the position quickly. Inspite of these weak points, this method is often used to measure the bed load discharge at an intermediate reach of a laboratory flume.

In relatively level fields, a basket type bed load sampler is often used, especially in a lower reach. But it is difficult to measure sediment discharge continuously by trapping.

In a mountainous stream, on the other hand, it is relatively easy to bypass sediment using an appropriate level difference. In Hotaka Sedimentation Observatory of Disaster Prevention Research Institute, Kyoto University, several methods have been devised to measure sediment discharge, some of which have been used effectively for many years. One of the major features of Hotaka methods is to obtain data not only continuously but also automatically.

In this study the author imported and improved Hotaka methods to a flume in the Ujigawa Hydraulics Laboratory of D.P.R.I., Kyoto University.

As one of the indirect measurement techniques, the idea to utilize a microphone confined in a pipe was proposed by a comittee of the Ministry of Construction. In this study, the author added some improvements in order to apply this method to actual use.

Most of this study has been published in Japanese as a two-part paper in the Annual of Disast. Prev. Res. Inst., Kyoto Univ.[5),6)]. This paper is an expanded translation of that study.

2. Direct measurement

When we measure sediment discharge in our laboratory, we usually put a sieve at the tail of the flume for a while, and then shift the sediment into a measuring container to detect its volume or weight. In some cases, we measure its submerged weight together with the sieve or the container.

If the rate of sediment discharge permits, we can measure the accumulated weight without removing the sediment. But when the accumulation is large, the sediment must be removed from the container. Although the procedures themselves are not so complex, modification of the process would be necessary if it were to be automated.

Fundamentally, it is desirable to remove the sediment without having to move a heavy cumbersome sieve. For this purpose, an inclined sieve is effective for conveying the sediment automatically. However, if the sieve is fixed, it is easily clogged by fine sediment or silt. In manual operation, this silt deposit is removed by turning the sieve upside down and giving it a strong shock. But such procedures are rather difficult to automatize.

2.1 The first device

In our first device (**Fig. 1**), a fixed, inclined sieve with 0.3 mm mesh, was used to separate sediment from water. In order to adjust the amount of water passing through the sieve, a sliding gate was set beneath the sieve. If the opening of this gate is too small, too much water would flow downstream. By this gate, the rate of flow was controlled so that there would be sufficient force to carry the sediment downstream. Moreover, as the sieve was easily choked by fine sediment, the discharge passing over the sieve was unstable. Therefore the sediment was once dropped into a vertical cylinder with the excess water and then pumped up by a small pump with an almost steady discharge which kept the mesh clear of silt.

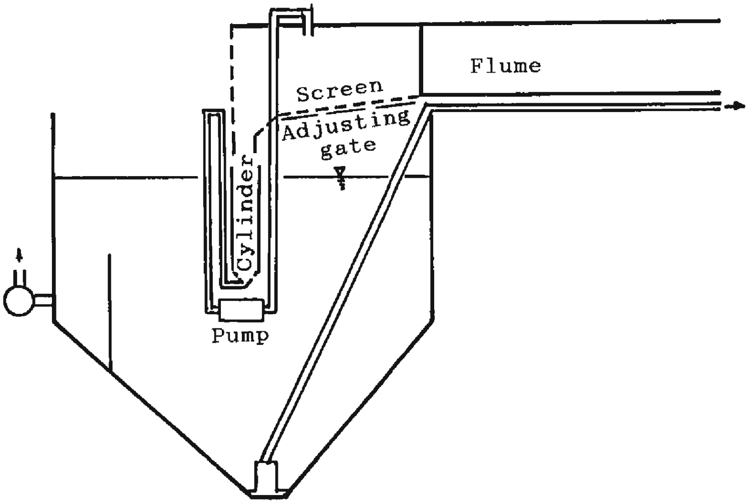

Fig. 1. Sand trap and conveying system of the first device.

After being pumped up to an appropriate position, the sediment is again separated from water using a small basket of about 2 liters (**Fig. 2**). After a one minute interval, the pump pauses and the basket is quickly replaced with another by the automatic movement of the conveyer belt. At the second position, the filled basket is hung to a load cell and the weight of the basket with wet sand is recorded on a chart. At the third position, the sediment is emptied by gravity and finally at the fourth position, the basket is cleaned by a shower. In this device, five baskets are connected by a motor-driven belt with the pump, belt, lever and shower being all controlled by microswitches operated by cams connected to another motor.

Fig. 3 shows the grain size distribution used in the test run. **Fig. 4** shows an example of the output voltage of the load cell recorded on a chart. At $t=0$ a basket was conveyed to the position just below the load cell. At $t=10$ sec, as the load cell is lifted up by

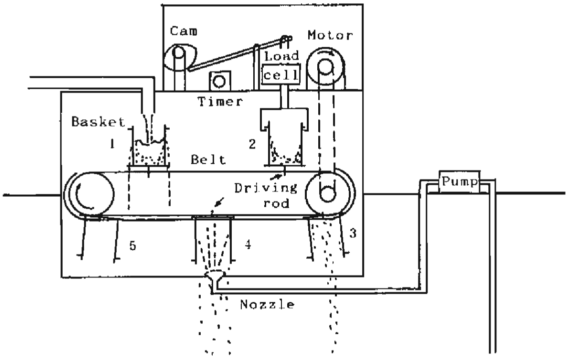

Fig. 2. Weighing mechanism.

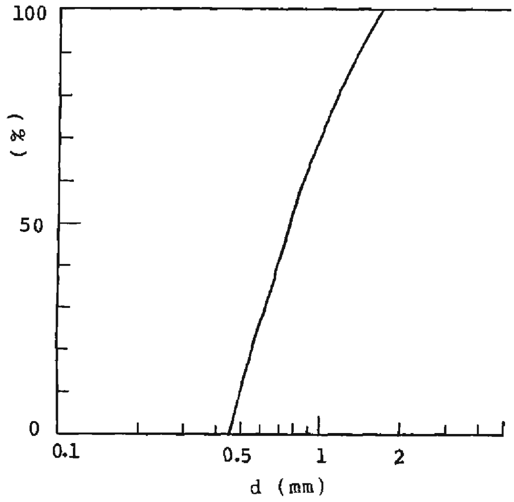

Fig. 3. Grain size distribution of sand.

a lever, the output suddenly increases, then soon gradually decreases. This decrease is brought about by the draining of water during the measurement. There is a small step, about $t=15$ sec, which corresponds to the turning point from upward to downward motion of the load cell. This step is perhaps caused by the viscosity of the water in the space between the driving rod and the belt.

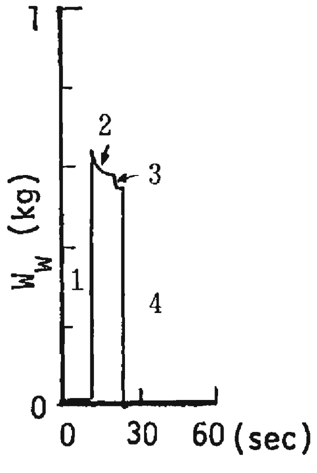

Fig. 4. An example of the output voltage of the load cell.
1: Sudden increase caused by the separation from the belt
2: Gradual decrease caused by the drainage of water
3: Step caused by the turning of the direction of motion
4: Sudden decrease caused by the sitting on the belt

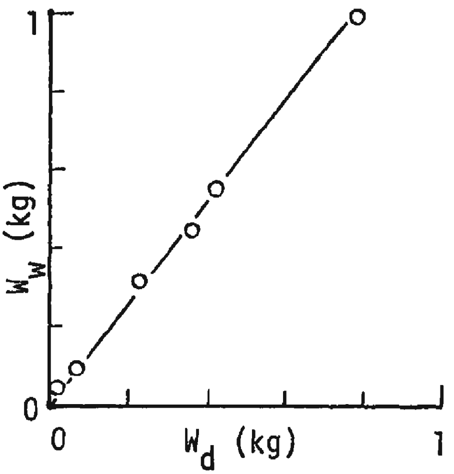

Fig. 5. A calibration curve between the wet and dry weights.

If the timing of the measurement is fixed, the amount of drain water depends almost on the amount of sediment. Therefore, a definite relation is expected between the wet and dry weights of the sediment. In this study, 20 sec was chosen as the drain time. **Fig. 5** shows a calibration curve obtained in an experimental condition without any flow from the main flume. In this calibration, a certain known amount of dry sand was thrown into a basket at position 1. According to **Fig. 5**, the detected wet weight is 1.25 times the dry weight +/−25 g. But this relation may be affected by the size distribution of the sediment.

Next, the time response of the system was checked by throwing a known amount of sediment at the downstream end of the flume. **Fig. 6** shows the time change caused by the known amount of added sediment detected by this system. Irrespective of the amount of sediment added, almost all of the sediment is conveyed to the basket within

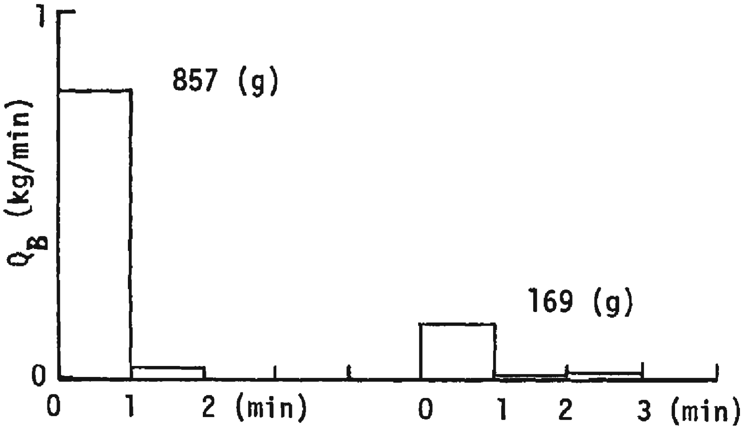

Fig. 6. A check of the time response of the equipment.

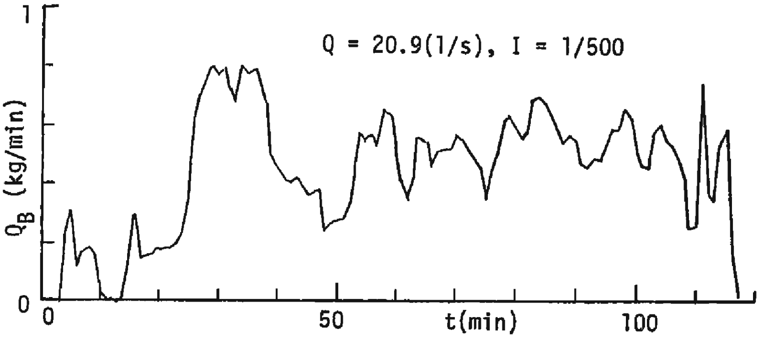

Fig. 7. An example of the time change of the sediment discharge measured by the first device.

the first minute.

Fig. 7 shows an example of time change of the sediment discharge measured by this device over two hours under the condition $Q=20$ l/s and $I=1/500$. Under this condition, the bed configuration is dune-like and the fluctuation shown in the figure is considered to be caused by the passage of dunes.

As mentioned above, the time change of sediment discharge is measured automatically by this device, but there are some problems with it. The most significant problem is the clogging of the sieve. The second problem is the clogging of the pump or pipe. The third problem is the overflow of excessive sediment from the basket. And the fourth problem is the lack of accuracy in weighing a small amount of sediment. These problems do not always occur but the applicability of this system is limited by them into the following ranges: $Q<20$ l/s, $Q_s=0.2-1$ kg/min and $d=0.4-2.0$ mm.

2.2 The second device

In order to improve the shortcomings of the first device, the second one was devised as shown in **Fig. 8**. First of all, the fixed sieve was replaced by an inclined trommel, 60 cm in diameter and 110 cm in length. Its inclination is 9 degrees and the rotation speed is 9 rpm. Using this trommel, almost all water falls through the sieve of 0.3 mm mesh. When the sediment includes gravel larger than several millimeters, the fragments do not stick to the sieve and readily move out at the downstream end of the trommel within the seconds. But when the sediment is fine and relatively uniform, it easily sticks to the sieve and is lifted up with the rotation of the trommel. In that case, it takes longer for the sediment to reach downstream. Therefore, in order to enable the sediment movement, a small shower nozzle is added near the entrance of the trommel.

The second point of improvement is the conversion from intermittent measurement to a continuous one. Just at the tail of the trommel, a tipping bucket with a diameter of 20 cm and a length of 25 cm is hung to a load cell, whose capacity is 5 kg and with an accuracy of 0.3%, full acale. The bucket has 4 compartments separated by a porous board, with a wire screen bottom. The critical tipping moment can be set arbitrarily from 0.5−2 kgcm by adjusting the position of a pair of counterweights. The total

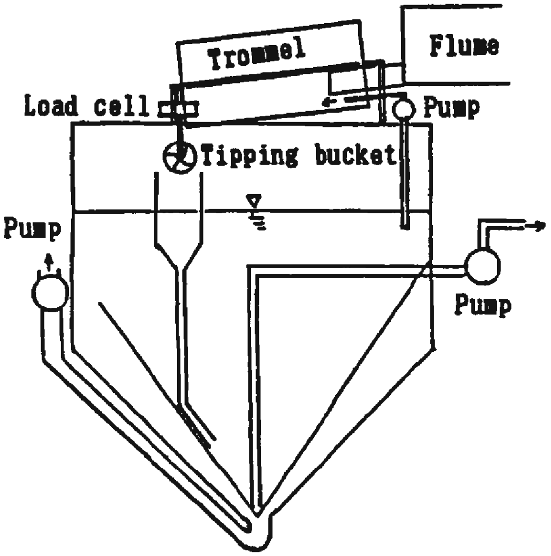

Fig. 8. Second device for direct measurement.

weight of the bucket and sediment is designed not to exceed the capacity of the load cell.

Fig. 9 shows an example of the output data from the load cell. The scattering of the critical weight of the tipping comes from the deviation of the center of mass of the sediment. And the scattering of the weight just after the tipping comes from the sticking of some sediment to the screen. Because of these scatterings, it is not good to estimate the sediment transport rate by counting the number of tippings. The sediment transport rate is estimated by the time derivative of the curve.

This device has been working well up to a flow rate of 40 l/s. But sometimes fine

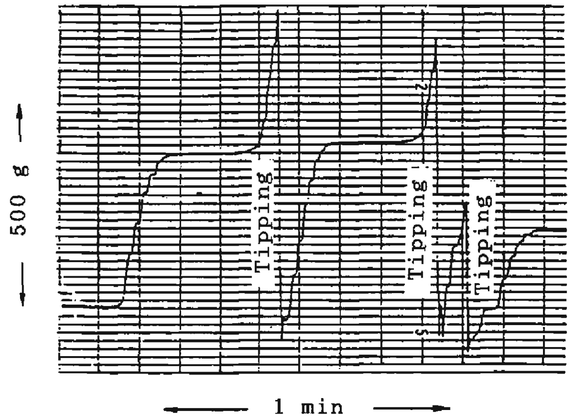

Fig. 9. A sample record of the output from the load cell.

sediment jams a bearing which obstructs the smooth tipping of the bucket. When the sediment transport rate is too high, the bucket continues to rotate without a complete stop. In order to escape this problem, it may be better to control the rotation of the bucket not by the balancing of counterweights but by a direct driving force such as a motor.

3. Indirect measurement detecting sounds

3.1 Principle

It is well known that sound is generated by sediment transport and some efforts have been made to detect and employ sound. However, there has been no practical success because the sounds generated by sediment do not quantitatively nor qualitatively give accurate data. For example, it is difficult to distinguish the sounds generated only by the sediment in motion from the surrounding noise. Perhaps these difficulties arise from detection methods based on sounds generated under natural conditions. Basically, with such detection methods, we passively accept sound without any positive attempts to alter and control sound so that it becomes a useful, measurable parameter. If we would actively control the sounds that we desire to measure, it may be expected that the measurement would become both easier and meaningful.

As one method to control and abstract the sounds associated with sediment motion, detecting the collision of particles by a microphone in a closed pipe has been considered. The oscillation of the air in the pipe is caused by the collision of the particle on the pipe. We can control the mode of collision and the sound by designing the shape, material, position of the pipe and the movement of the sediment itself.

The characteristic frequencies of the first mode of air oscillation in the peripheral, radial and axial direction in a closed pipe are represented by

$$f=0.298\,c/a \qquad (1)$$

$$f=0.61\,c/a \qquad (2)$$

and

$$f=c/(2l) \qquad (3)$$

respectively[7]. Where, c is the sound velocity in the air, a is the radius and l is the length of the confined space of the pipe. Except for the instant of the collision, the oscillation of the air in a pipe is mainly characterized by these basic modes.

On the other hand, the energy density of the echo in a room with volume V and surface area S is represented by

$$\varepsilon=\varepsilon_0\exp(-13.6\,t/T) \qquad (4)$$

and the characteristic time of the echo is represented by

$$T=0.16\,V/(kS) \qquad (5)$$

where ε_0 is the initial energy density of the sound and k is the average absorption rate. Controlling this characteristic time to match the frequency of the collision, increases the efficiency of measurement.

ε_0 depends on many factors such as the velocity, mass, position and angle of collision, but in the case of coaxial collision, it is proportional to the momentum of the particle. Therefore, if the particle collides coaxially to the pipe and the velocity is known, it is possible to estimate the particle mass from the value of ε_0. If the collision angle and velocity are not constant, the relation between ε_0 and the mass varies widely. But even in that case, it is possible to estimate the distribution of the particle mass from the distribution of ε_0 statistically.

3.2 Flume test of the sound method

In order to test this method of sound detection, some pipes each containing a microphone were set in a flume 30.7 cm wide and 12 m long as shown in **Fig. 10**. Briefly, on the bottom of the flume, 4 cm thick pieces of wooden board were layed. On the top of pieces A–D, a pair of pipes with microphones were horizontally buried so that just half of each pipe was exposed. Each pipe is 30 cm long and the length of the inside space is 25 cm. At the both ends of the space, a soft, sound absorbant material was set. Diameter and wall thickness of the pipes differ among the pieces A to D: in A, $d_0=1$ cm, $s=1.5$ mm; in B, $d_0=1$ cm, $s=2$ mm; in C, $d_0=3$ cm, $s=2$ mm; and in D, $d_0=3$ cm, $s=3$ mm, where d_0 is the outer diameter and s is the thickness of the pipe wall. The size of each microphone is 5.6 mm × 7 mm and has an effective range of frequency of 50–15000 Hz. Moreover, the pipes were fixed tightly to the each board directly by a steel

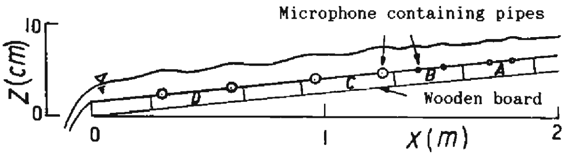

Fig. 10. Pipes arrayed along the flume bed.

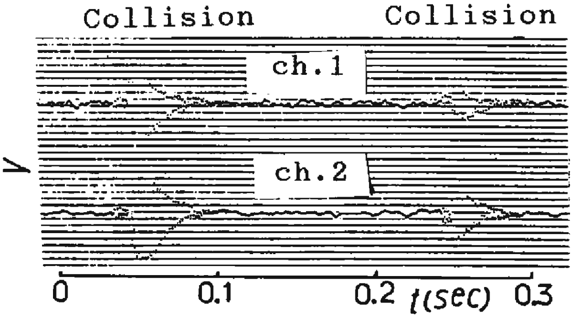

Fig. 11. A sample record of the output from the microphone.

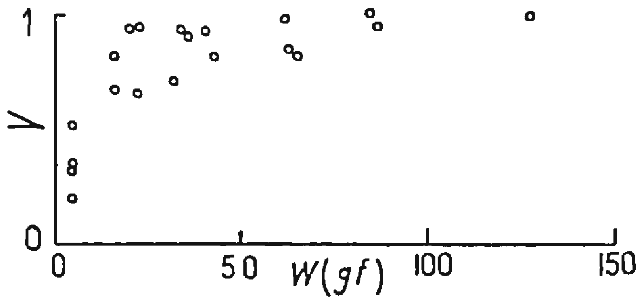

Fig. 12. A plot of the maximum amplitude versus particle weight.

belt.

Fig. 11 shows a sample record of the output from the microphone which was recorded in a magnetic tape and monitored by a visigraph thereafter. Ch. 1 corresponds to the upstream pipe and ch. 2 corresponds to the downstream pipe in the same piece. The wave pattern at the moment of the collision differs significantly from that at the other time. Therefore it is relatively easy to find out the collision of the particle from this chart by eye. But in this experiment the sound was detected not only when the particle hit the pipe but also when it collided to some other part of the bed. We cannot estimate the amount of sediment discharge simply from the number of collision-like sound. In order to detect only collisions to a specific pipe, it is necessary to isolate each pipe acoustically from the bed.

Fig. 12 shows the relation between the maximum amplitude of the sound and the particle weight. There is considerable correlation between them. The amplitude slightly depends on the thickness of the pipe wall, but the time of the echo does not significantly depend on that. When the diameter of pipe is too small, the particles are apt to pass over it without collision, and when the diameter is too great, this is apt to dam up the flow and create a big wake behind it. These phenomena depend not only on the dimension of the pipe but also on the flow conditions and the particle size.

The preferable dimensions and configuration of the pipe are to be considered in future. As the sediment discharge increases, the time interval between collisions becomes short, and it becomes difficult to distinguish each collision. Moreover, if the pipe is buried by sediment, this method cannot be applied. The solution to these problems are also subjects for future study.

3.3 Real time data processing

In the previous test, it was made clear that the size of the particle which hits the pipe can be estimated statistically from the amplitude of the sound detected by a microphone confined in a pipe. However, in order to utilize this method to quantify sediment discharge, it is necessary to process the data quickly. Because the sound data is at high frequency, the amount of data becomes overwhelming without real time processing.

Fig. 13 shows a typical wave pattern and its spectrum of a collision of a particle to a

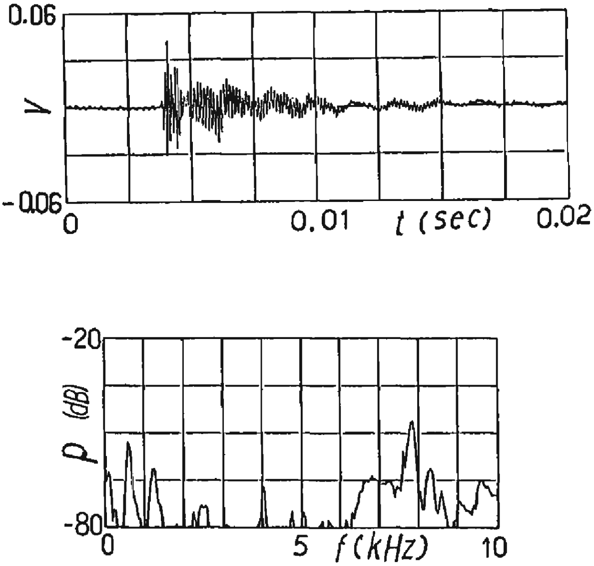

Fig. 13. A typical wave pattern and spectrum distribution.

3 cm pipe. In this case the output from the microphone was digitized by an A/D converter of 20 kHz. The sound included high frequency oscillation and decreased exponentially with time in about 10 milliseconds. The dominant frequency was about 8 kHz which corresponds to the base mode represented by eq. (1). The second peak appeared around 0.7 kHz which corresponds to the mode represented by eq. (3). It is not impossible but rather ineffective to digitize these data directly.

Using an analogue circuit as shown in **Fig. 14**, the wave pattern is converted as

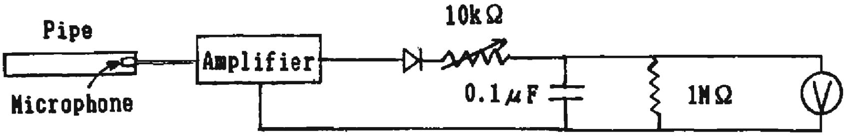

Fig. 14. An analogue circuit for pre-acquisition of data.

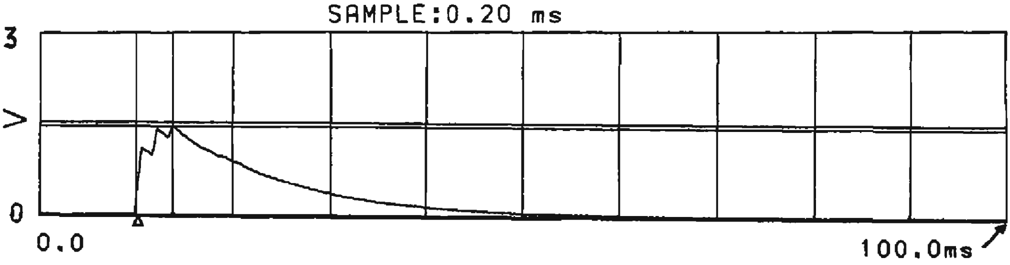

Fig. 15. A sample record obtained through the analogue circuit.

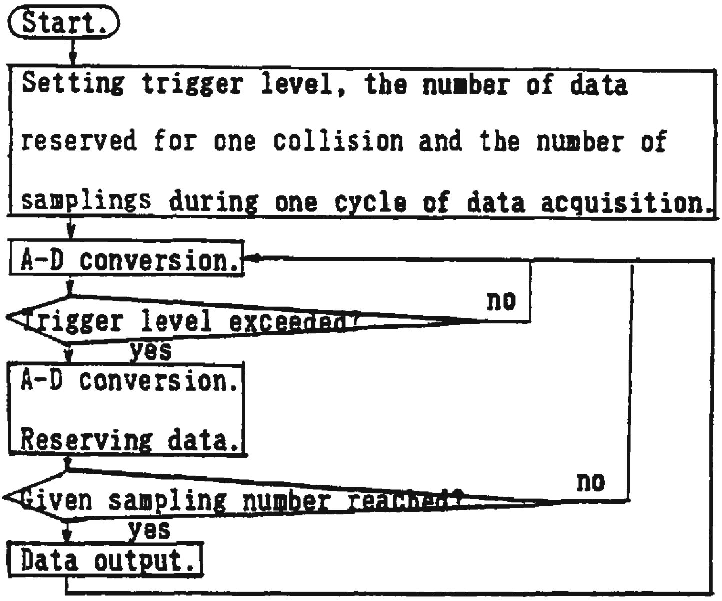

Fig. 16. The flow chart of real time processing of data.

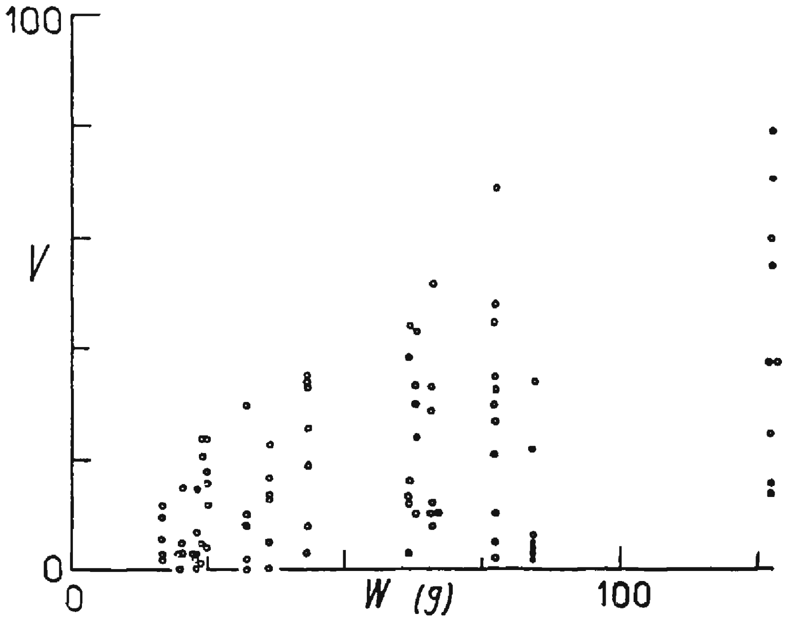

Fig. 17. Data for the case in which particles were supplied separately.

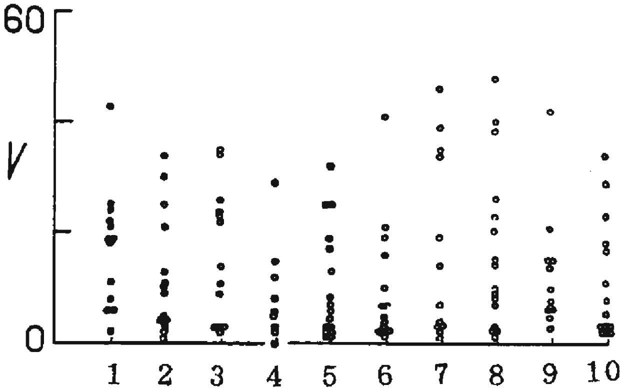

Fig. 18. Data for the case in which 16 particles were supplied simultaneously.

shown in **Fig. 15**. Doing so, it becomes easier to digitize and detect the maximum or mean amplitude. **Fig. 16** shows the flow chart of real time processing of the data using a personal computer.

Fig. 17 shows the result of a test run in which 16 particles were separately thrown into the flow under the condition $B=15$ cm, $I=1/20$ and $Q=8$ l/s. The abscissa represents the weight of each particle, and the ordinate represents the average output during about 10 ms normalized by the trigger level. Using the same set of particles, the test was repeated 10 times. In this experiment, the pipe was fixed to the bottom inserting a sponge sheet to insulate the pipe acoustically from the bottom. For large particles, all passes were detected but as the particle size decreased the chance of non-detection increased. Particles lighter than 3 g were not detected. As there is a significant scattering even for the same particle, it is impossible to specify the particle size definitely from these data. This is perhaps based on the scattering of the velocity and the angle of collision. But in a statistical sense, there was a significant correlation between the sound output and the particle weight.

Fig. 18 shows the data obtained in the case where the 16 particles were thrown into flow simultaneously. The test was repeated 10 times using the same set of particles. The abscissa represents the run numbers. In **Fig. 19** the sediment runoff estimated from **Fig. 18** combined with **Fig. 17** is compared with the sediment thrown into the flume. There is a considerable scatter in this case also, but statistically, it is possible to estimate the amount and size distribution of particles by this method, though it is necessary to calibrate for every hydraulic condition.

3.4 Improvement of the sound method

In the previous test, the scattering of the data was highly significant, which was mainly brought about by the irregularity of the velocity and the angle of collision. In light of this, the author devised quite a different arrangement of the pipe as shown in **Fig. 20**. At the downstream end of the flume a sieve screen was set. Particles lost their velocity when they hit the sieve, and they began to fall almost vertically. At an ap-

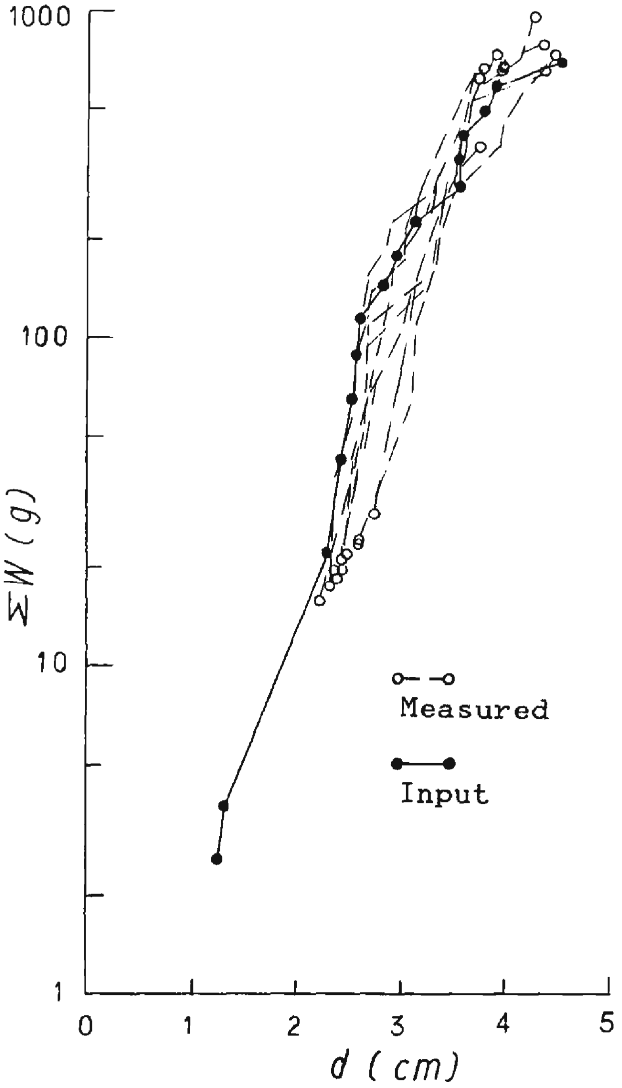

Fig. 19. The amount and size distribution of sediment estimated from Figs. 17 and 18.

propriate height, an inclined plastic board was set, behind which a pipe with a microphone was firmly attached. This pipe is isolated acoustically from the flume and the supporting frames. When a falling particle hits the plastic board, its angle and velocity were almost constant irrespective of its shape, size and flow conditions. Therefore, the impact of the particle was proportional to the mass of the particle. Of course, the trajectory of the particle slightly scattered so that it was necessary to make the board appropriately larger. The acoustic characteristics of the board depends on its material, shape, size and supporting method. Considering the appropriate amplitude

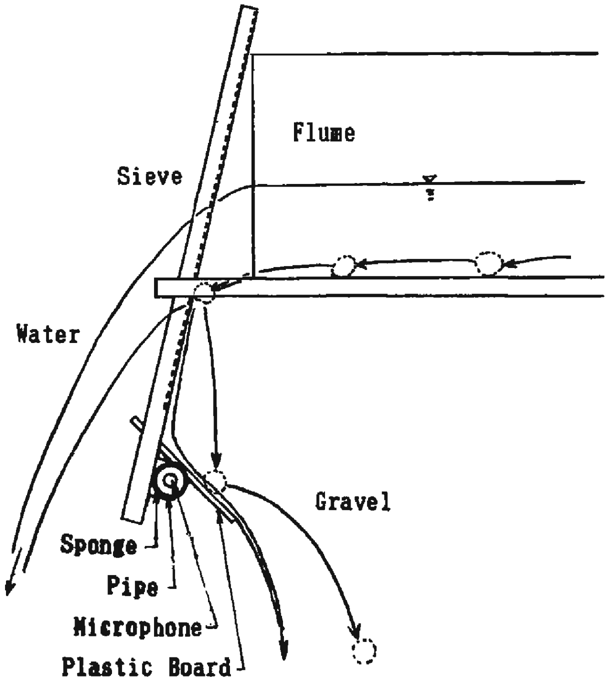

Fig. 20. Arrangement of the sensor in the improved system.

and echo time, a square plastic board 15 mm thick, 20 cm wide and 15 cm long was used in this experiment.

Fig. 21 shows the data obtained in a similar test to that in **Fig. 17**. In **Fig. 21** the range of scattering is much reduced compared with **Fig. 17**. **Fig. 22** shows the data obtained in another test similar to **Fig. 18**. In **Fig. 23**, the sediment runoff estimated from **Fig. 22** combined with **Fig. 21** is compared with the sediment thrown into the flume. In this case, the amount and size distribution of the sediment were estimated more accurately than in the previous case.

In the laboratory flume this method was more effective than the previous one. However, in the field there would be great difficulty applying this method because fine sediment would easily clog the sieve screen. And as the natural power of a stream and its sediment is much larger, the screen is apt to be broken. In order to apply this method to the field, it is considered better to combine these two methods. For example, in one design a board is fixed, below which a pipe with a microphone is attached, in a channel bed. However, this and other designs have yet to be tested.

4. Conclusion

In this study, some new measurement techniques, both direct and indirect, for sediment discharge have been devised.

In the direct method, two devices were constructed. The first one had a fixed inclin-

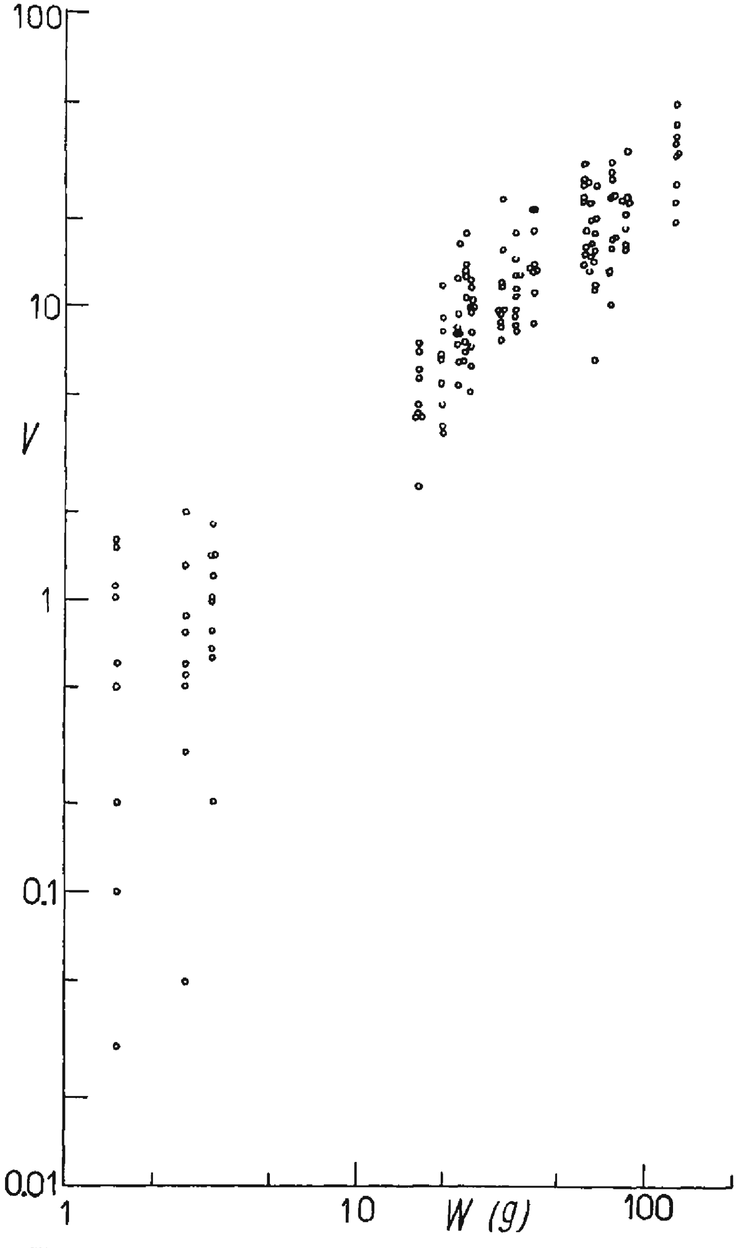

Fig. 21. Data for the particles supplied separately in the improved system.

ed 0.3 mm mesh screen, pump and five baskets shifting position by a motor driven belt. In each basket, sediment collecting, weighing, evacuating, washing and waiting were repeated in turn with a time interval of 1 min. With this divice, the time change of sediment discharge caused by the passage of dunes was clearly detected. However, there

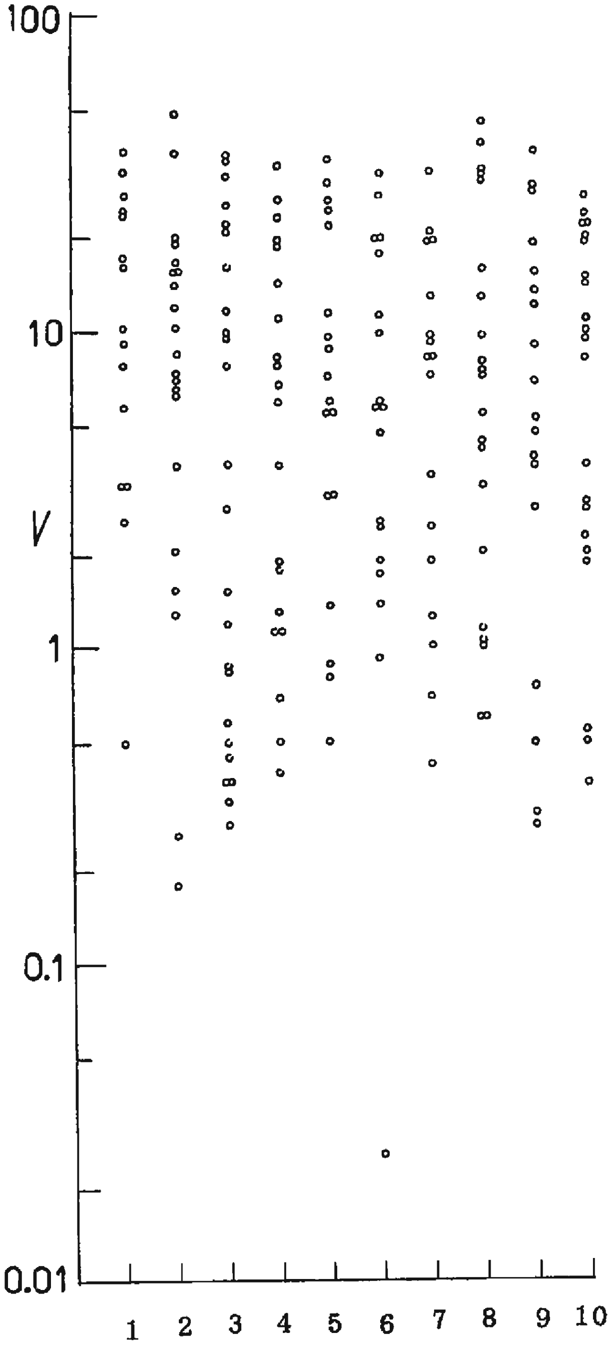

Fig. 22. Data for the particles supplied simultaneously in the improved system.

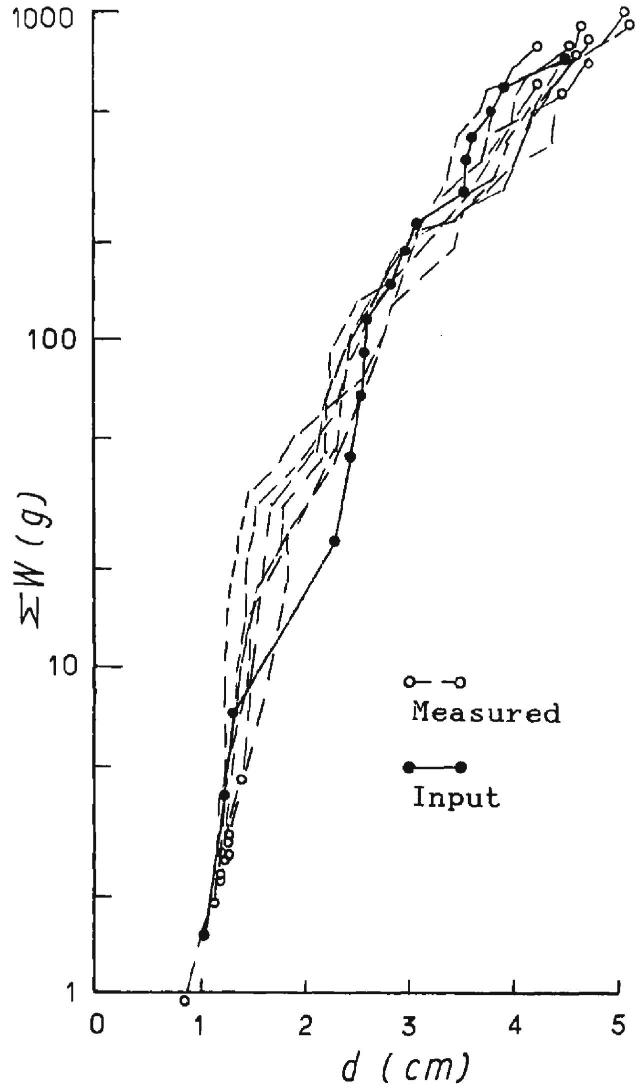

Fig. 23. The amount and size distribution of sediment estimated from Figs. 21 and 22.

were some problems in this manufacture. The most significant one was the clogging of the sieve, followed by the choking of the pump or pipe. A third problem was the overflowing of the basket. And finally, there was the lack of accuracy when weighing a small amount of sediment. Because of these problems, the applicability of this system was limited in the range $Q<20$ l/s, $Q_s=0.2-1$ kg/min and $d=0.4-2.0$ mm.

In the second device, a trommel and a tipping bucket hung to a load cell were used referring to the system of the Hotaka Sedimentation Observatory in Gifu Prefecture. This combination has been found to work well for sand and small gravel for a flow rate up to 40 l/s. But sometimes fine sediment gets jammed in a bearing which impedes the smooth tipping of the bucket. Furthermore, when the sediment transport rate is too high, the bucket continues to rotate without a complete stop. In order to escape this problem, it is supposed to be better to control the rotation of the bucket not by the balance of counterweights but by a direct driving force such as a motor.

As an indirect method, the author tested the idea of utilizing a microphone confined in a pipe which was originally suggested by a comittee of Ministry of Construction which was considering methods to measure sediment discharge. Applying this method, the sound generated by the collision of gravel is clearly detected. By analyzing this sound, the amount and the size distribution of the gravel can be estimated with the aid of some calibration. However, when the pipe was set on the surface of the bed, the velocity and angle of collision of particles scattered so much that their statistically determined properties strongly depended on the flow conditions.

When the microphone containing pipe is attached to a board which is set at an appropriate height at a step-down such as the downstream end of a flume, the scatter reduces and the statistical properties no longer strongly depend on the flow conditions. In that case, however, this setup is apt to be easily broken by the strong impact of the particles. More improvement is needed.

With this in mind, the sound method will be applied in the upper Joganji River, in Toyama Prefecture, in 1990. A report on this project and other applications will follow.

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