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OBSERVATIONS AND ANALYSES OF FINE GRAINS IN FLOOD FLOWS AT THE ABUKUMA RIVER MOUTH

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Abstract

Vertical distribution of fine grain sediments have been observed during floods by using a specially designed sampler at the Abukuma River mouth. The samples were analyzed through the Coulter Counter to obtain the grain size distribution. For each grain size range, the observed vertical distributions of the concentration are compared with Rouse's solution. The reference concentration at 5% of the depth from the bottom extrapolated by the solution are compared with Lane's formula using the grain size distribution of the bed materials which was also taken during the flood. Also the relationships between the reference concentration and discharge for each grain size range are presented.

KEYWORDS: *the Abukuma River, floods, grain size, wash load, reference concentration*

1. Introduction

Afforestation and construction of dams in a catchment reduce the yield and transport of coarse grain sediments and increase the portion of fine grain sediments which may be yielded by the soil erosion and weathering. Most of the fine sediments start to move by intense rainfall and the flow, and are carried by the runoff to go out to the sea through the river mouth. Having low settling velocity, the fine sediments in the sea spread widely due to the efflux of river water, tidal current and also ocean current.

Furthermore phosphorus which is supplied through agricultural activities is adsorbed to the surface of the fine grains having huge surface area. Therefore the phosphorus is mainly transported with the find grain sediments and then diffused in the sea. This material is the main source to cause the eutrophication when it is accumulated.

The flux of material transport at the river mouth is the integrated information of the watershed and becomes boundary conditions representing the natural and mortal activities in the catchment when we consider the environment of the coastal zone or ocean further. Among the materials of water, sediments and chemicals, the sediments are especially important because they are not only pollutant in themselves but also transporter of other pollutants.

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2. Outline of the observations

Since 1994, we have been observing fine grain sediments in flood flows of the Abukuma River, at the Abukuma Bridge point, 8 km upstream from the river mouth, by using a hand-made sampler. This point has several advantages in the observation and the analysis of the observed data; (1) that a side walk attached in the down stream side of the bridge enables safe working apart from automobiles, (2) that hydraulic conditions, such as time histories of water surface elevation and discharge, are available owing to the observation conducted by the Japanese Ministry of Construction, which has been performed once an hour over forty years near the point, (3) the effect of tidal intrusion is small here.

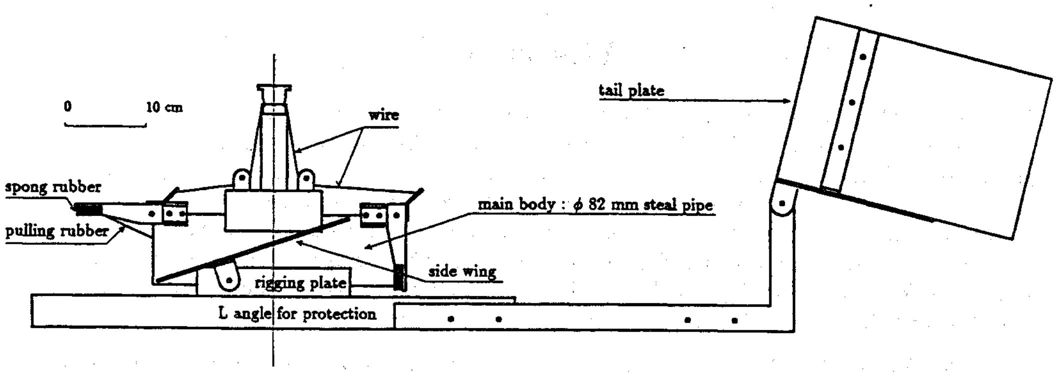

Figure 1. Dimensions of the sampler.

The sampler was specially designed for the use during floods as shown in Fig. 1. In order to handle it easily in heavy storm weather, we have developed a light weighted sampler of an instantaneous trap type. But, the lightness gives rise to new difficulties. Due to fast flows of floods, the sampler connected with a rope and dropped off from the bridge is quickly carried downstream and is difficult to drive into deep water. Furthermore, since the rope dose not stretch vertically, we need the other way to know the vertical position of the sampling point besides the length of the rope. For the first matter, we searched appropriate wings that generate downward lift from the flood flow and let the sampler drive downward, and have attached them. For the second matter, we have developed the manometer that memorizes the pressure at the sampling point. Further information on the sampler is described in Mano *et al.*(1994, 1996) .

So far, we have performed observations of the four floods on September 29 to 30, 1994 with the peak discharge, Q_{max} = 2,800 m^3/s, May 13 to 14, 1995 with Q_{max} = 700 m^3/s, August 3 to 4, 1995 with Q_{max} = 1,000 m^3/s and September 17 to 18, 1995 with Q_{max} = 1,900 m^3/s. The sampler has been improved while being applied to these floods. For the first flood, the wings were not so proper that the measuring point reached at most 2 m below the surface. Figure 2. shows the cross section at the Abukuma Bridge and the measuring positions, No.1 and No.2.

The river bends slightly to the right around here. This corresponds to the saw tooth-like section of the channel. Figure 3. shows the hydrograph and the bottom shear velocity of the third flood, August 1995. Where the shear velocity, u^*, is calculated by assuming the normal

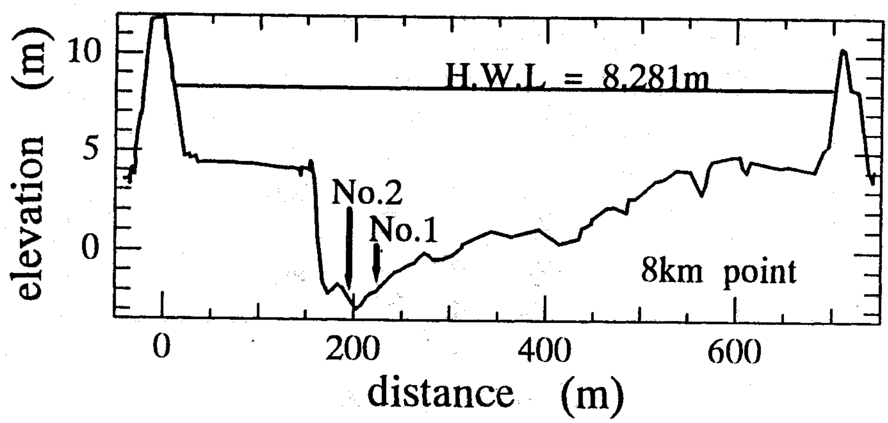

Figure 2. Cross section and observing points.

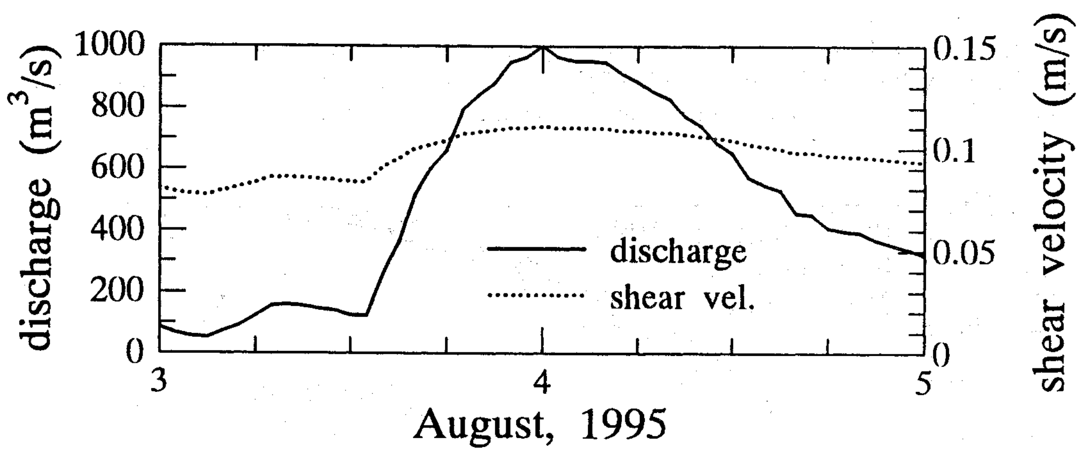

Figure 3. Time history of discharge and shear velocity.

flow as $u^* = \sqrt{ghI}$, with the gravitational acceleration, g, the local depth at the measuring point, h, and the average bottom slope, $I = 1/4000$.

Figure 4. shows the measuring points as well as water surface in time-space plain for the flood. The lowest point of the measurements is very near the bottom of the elevation, -2.2 m above the mean sea level. This is realized by improving the wings. Furthermore all the measuring points were covered by one sampler. Since it takes about five minutes to get one sample, such covering of many sampling points becomes possible.

3. Grain size distributions

The samples were analyzed for two items; concentration on a mass basis and grain size distribution. For the former item, a specified amount of the sample was leached with the filter of pore size, 1 μm, and the mass remained to the filter was measured after being dried. For

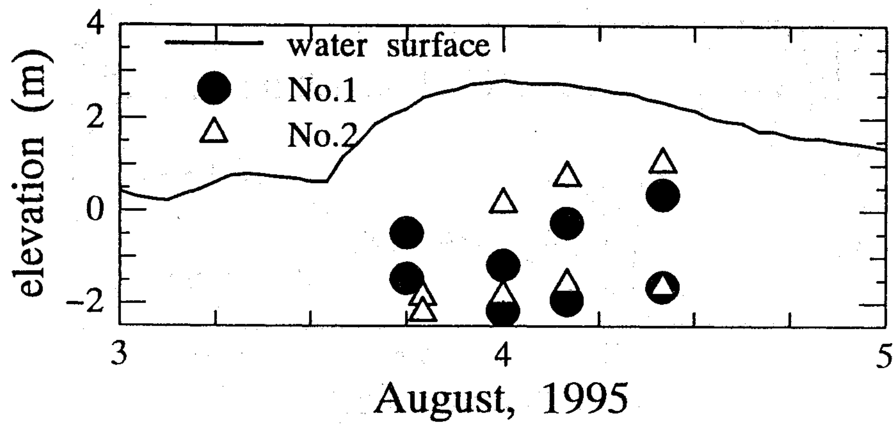

Figure 4. Sampling points.

the latter, we used the Coulter Counter. This equipment counts the number of grains for each range of grain volume and gives outputs of the grain size distribution. Here the grain size is the nominal diameter, the diameter of a sphere having the same volume.

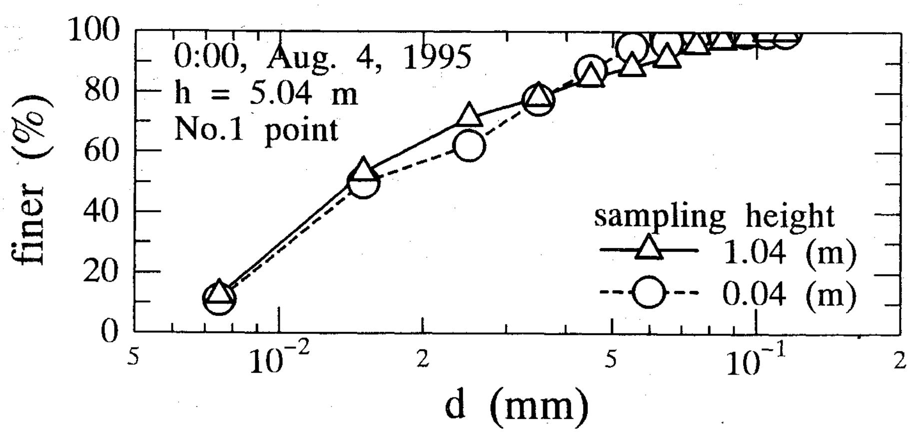

Figure 5. Grain size accumulation curve of sediments in suspension.

Changing again from grain size to volume and multiplying the volume by the number, we get subtotal of the volume in each range of grain size, then the volumetric frequency distribution. The integration of the frequency gives grain size accumulation curve as shown in Figure 5. Two curves for the positions, 0.04 m and 1.04 m above the bottom are drawn. For both positions, the maximum grain size is about 0.1 mm and the median diameter is about 0.015 mm. Therefore the sediments are classified in the categories, the clay, silt and very fine sand according to the AGU grade scale. For the grains coarser than 0.1 mm, the Coulter Counter could not count numbers, because the number densities are very low.

As for such fine grain sediments, there is another important classification whether wash load or bed-material load. The wash load may be defined as the fine material, not available in the bed of the stream near the point of the observation, according to Vetter(1937). The boundary of the two loads is determined conventionally by the grain size. Many researchers, e.g., Muramoto *et al.* (1973), Rendon-Herrero (1974), and Kanayashiki *et al.* (1980), have proposed the boundary values, ranging from 0.1 mm to 0.2 mm. According to the values, the sediments observed in this study stay in the wash load.

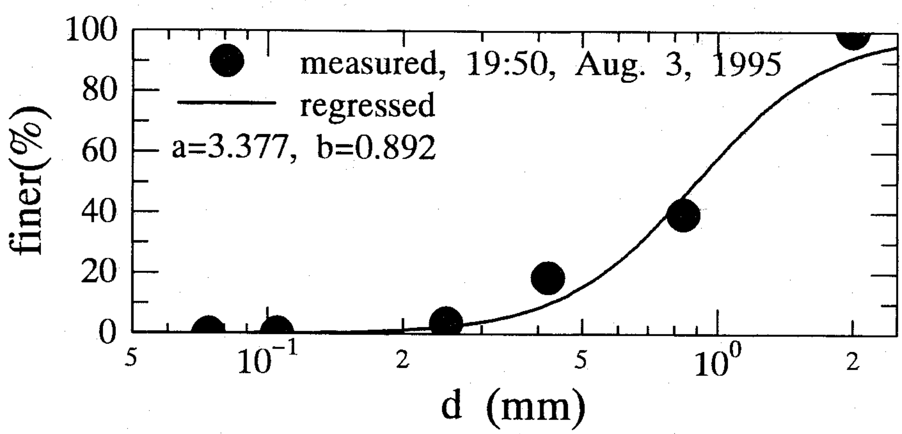

Figure 6. Grain size accumulation curve of bed materials during the flood.

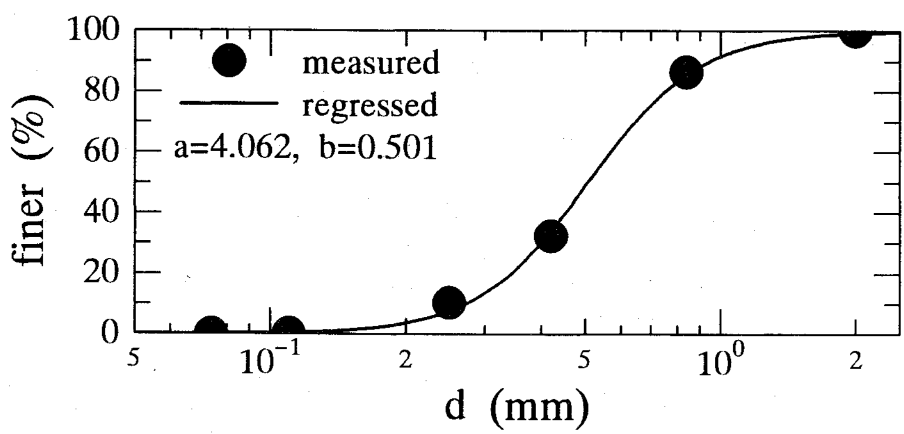

Figure 7. Grain size accumulation curve of bed materials for the common flow.

In order to examine the above classification, the grain size distribution of the bed materials as well as in water is needed. During the flood of August, 1995, we managed to get the bed materials by letting the sampler thrust obliquely into the river bed. Judging from the volume obtained, it is estimated that the materials were taken from within ten centimeter of the bed surface. By sieving the materials according to JIS A1204, we obtained grain size distributions. The cumulative frequency distributions of the flood time together with the usual time are shown in Figs. 6 and 7, respectively. The smooth curves drawn in these figures are the least square fitting of the function;

$$y = 50(1 + \tanh(a \log_{10}(\frac{x}{b}))).$$

Where a and b are the parameters to be determined from the observed data. a indicates the width of the distribution, while b the median diameter. Since there are few sieves below 0.1 mm in size where most of the observed sediments in water exist, we employed this function in order to compare two kinds of the distributions. For the observation of the usual time, this function fits the data with good satisfaction. The median diameter is 0.50 mm. On the other hand, for the flood time, the fitness diminishes and the median diameter increases to 0.89 mm. The change of the diameter corresponds to the phenomena that high shear stress of the flood picks up the fine grain sediments selectively and carries out, then they are recovered by deposition in the later stage of the flood.

4. Vertical distributions of sediment concentration

For the evaluation of overall flux of sediments in a cross section, vertical distribution of the sediments is especially important. To get such information, we gathered data for the flood of May 1995, by sampling at three vertically different points. After analyzing the grain size distribution, we integrated the distribution into four subranges; 0.050-0.024mm, 0.024-0.048mm, 0.048-0.074mm and 0.074-0.105mm. The relationships between relative volumetric concentration, C/C_A, and relative height, y/h are shown for the subranges in Fig. 8. Where the height y is taken vertically upward from the bed, h is the water depth, C_A is the observed concentration at the lowest point $y = A$. The finer the grain size gets, the more vertically uniform the distribution approaches.

The solid curves in these figures are the theoretical results obtained by Rouse (1937), assuming the equilibrium between settling and diffusion of the sediment. It is written as follows;

$$\frac{C}{C_A} = \left(\frac{h-y}{y}\frac{A}{h-A}\right)^{w_0/\kappa u*}$$

Where $\kappa = 0.4$ is Karman's constant and w_0 the settling velocity given by Rubey's formula (Rubey 1933) by using the median diameter of the subrange.

The observed data are close to the theoretical results of Rouse for all ranges. The distribution for the finest range is almost uniform, while for the coarsest size the relative concentration in the upper third is less than a half.

Although there are some exceptions, most of the observations yield the distributions similar to the Rouse's solution. This fact indicates that the equilibrium between settlement and diffusion of sediments is a good approximation throughout all ranges of the size. Especially, in the coarsest range around 0.1 mm, the settling velocity reaches 1 cm/s. This leads that the settlement and then the upward flux of the load are not negligible.

Next remark is on the measurements. The measurements were made by one sampler at the vertically and also horizontally different three points with each interval of more than five minutes. Figure 8 is drawn by using the information only on the vertical positions, neglecting the difference of the horizontal positions and times of the measurements. This yields relatively good agreement with Rouse's result. The dominance of the equilibrium mentioned above results that if the channel section does not change abruptly, the distribution is nearly uniform in the streamwise direction, or if the flow condition does not change rapidly, the distribution

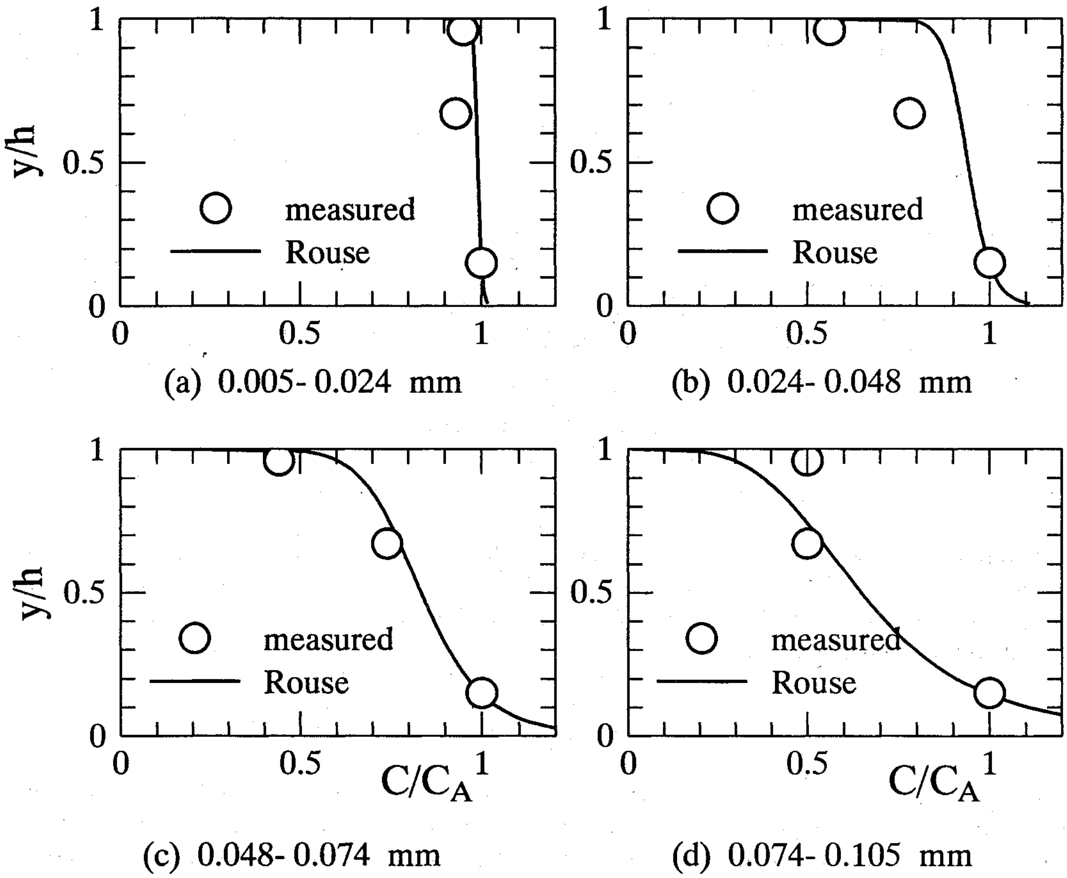

Figure 8. Vertical distribution of the relative concentration. (06:00, May 14, 1995)

is stable in time. In order to eliminate the fluctuations of the concentration due to the turbulence, sophisticated samplers of point integrating type have been developed, see for example, Kikkawa(1952), or van Rijn(1993). But as the compensations of the stability, the sampler of this type is complex in the mechanism and heavy. For the purpose of evaluating the sediment flux under the dominance of fine grain load, the sampler of this study would be sufficiently effective.

5. Reference concentration

From the grain size distribution of observed sediments in water, we have classified them into wash load. The American Geophysical Union defines wash load as "that part of the sediment load of a stream which is composed of particle sizes smaller than those found in appreciable quantities in the shifting portions of the stream bed" (Rendon-Herrero, 1974). Since we have obtained the bed materials during the flood on August, 1995, as mentioned in 3., we will at first examine the relationship between the bed materials and suspended materials.

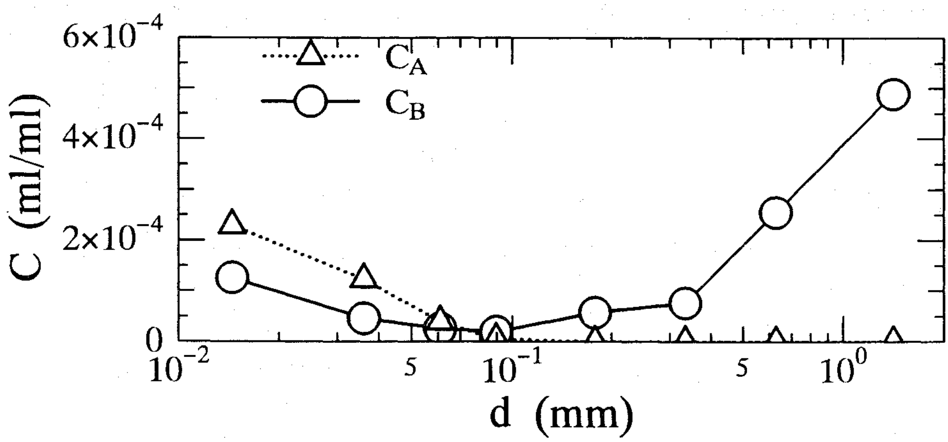

Figure 9. Reference concentrations, C_A and C_B.

Although the flood decreases fine sediments in the bed as seen from Figs. 6 and 7, there exists definite amount of sediments below 0.1 mm in diameter. Lane *et al.* (1939) have proposed the relation between materials in suspension and bed, based on the field data and it is often used still today. This is written as:

$$C_B = 5.55\Delta F(w_0)(\frac{1}{2}\frac{u^*}{w_0}\exp(-(\frac{w_0}{u^*})^2))^{1.61}.$$

Where C_B is the volumetric concentration of the sediments in suspension at the bottom in parts per million and $\Delta F(w_0)$ is the relative amount in per cent of the diameter which gives the settle velocity w_0. The comparison of C_A and C_B for each grain size is shown in Fig. 9 where C_A is the reference concentration, this time, at the height $0.05h$, which is extrapolated by using Rouse's solution, at 0:00, August 4, 1995. Although the positions of C_A and C_B are different, the difference in the concentration is small for the range $w_0/u^* \ll 1$, judging from Rouse's distribution. While C_B is computed by Lane's equation with the bed material distribution at 19:50 on August, 1995. C_A has good correlation with C_B below 0.09 mm and the ratio of the two quantities is about two.

Above 0.1 mm, we could not count the number of grains due to the very low grain number densities. The relation between grain diameter and the parameter, w_0/u^*, which is important in Rouse's as well as Lane's, is plotted in Fig. 10. The parameter increases with increase of the diameter, then the vertical distribution of the concentration becomes very sharp. Therefore if the sampling point is apart from the bed, the concentration decrease remarkably. Furthermore, since the grain volume is proportional to the cube of the diameter, the number of grains is proportional to the inverse of the cube of the diameter. So effective detection of grains by the counter requires a large quantity of the sample or high enrichment of the sample.

Ashida *et al.* (1982) have pointed out that the critical shear stresses for sediment motion and suspension agree at the grain diameter of about 0.1 mm, say critical diameter, d_c, and for $d > d_c$, the critical condition of suspension is approximated by $w_0 \sim u_c^*$, where u_c^* is the critical shear stress of motion. Since the shear velocity exceeds the settling velocity for $d < 1$

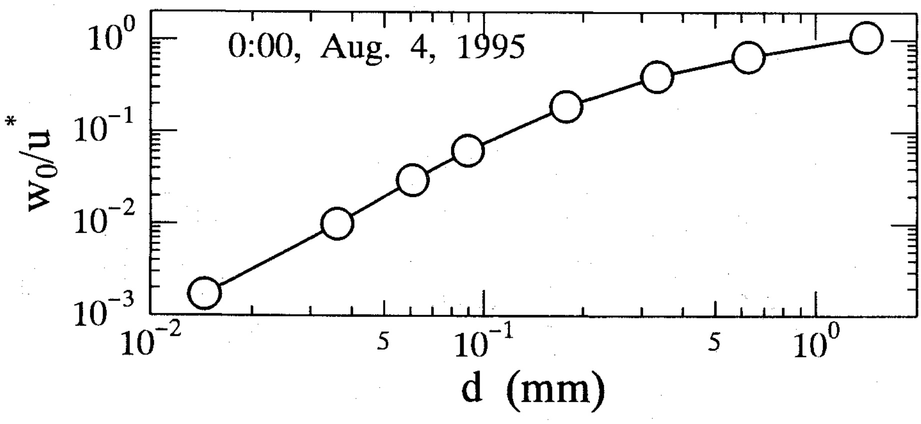

Figure 10. Ratio of w_0/u^*.

mm, in Fig. 10, the flow has enough traction to keep these sediments in suspension. Therefore, it is judged that no detection of the load in the range $0.1 < d < 1.0$ mm comes from insufficient analyses of the samples.

Einstein *et al.* (1953) conducted experiments on the behavior of wash load and have founded that the highly concentrated layer of very fine grain below 0.06 mm was formed on the bed surface and developed its thickness during the experiments. They considered that the reason why, in the actual river, wash load had not detected was on the difficulty of sampling such fine grains against the high speed flow, because the approach of the sampler to the bed may cause the fine grains to be blown off. Therefore, the definition on the unavailability for the wash load may not be appropriate. Their another finding is that the transport rate of wash load can be calculated from the Einstein bed-load function with the instantaneous bed composition. These results as well as Fig. 9 suggests that wash load leaves deposition to the bed, during floods, in such a amount that the bed load formulae can predict. But from the practical point of view to evaluate the sediments transported by floods, it is difficult to get bed compositions for various floods. The relation of the concentration to the discharge would be considered next.

The reference concentration at the $0.05h$ height is compared with the discharge for each grain size range in Fig. 11. The first flood of September, 1994 is the biggest among the observations, but its data is omitted because the sampling points were limited near the water surface in the first trial. Therefore the maximum discharge is about 2000 m^3/s. As the diameter increases, the concentration decreases, which is also recognized from Fig. 9. If we combine this reference concentration with the vertical distributions of the concentration as well as the velocity, we can find the major part of the sediment flux is occupied by the finest range. This figure also shows regressed lines crossing the origin as a physically obvious point. Although there are some exceptions especially for the larger particles in the flood of September 1995, the concentration increases with the discharge. Since the fine particles are carried distantly, the characteristics of the catchment influences the concentration. This leads that the precipitation distribution in the catchment also affects the concentration. The scatter from the regression line in the figure shows some bias due to each flood.

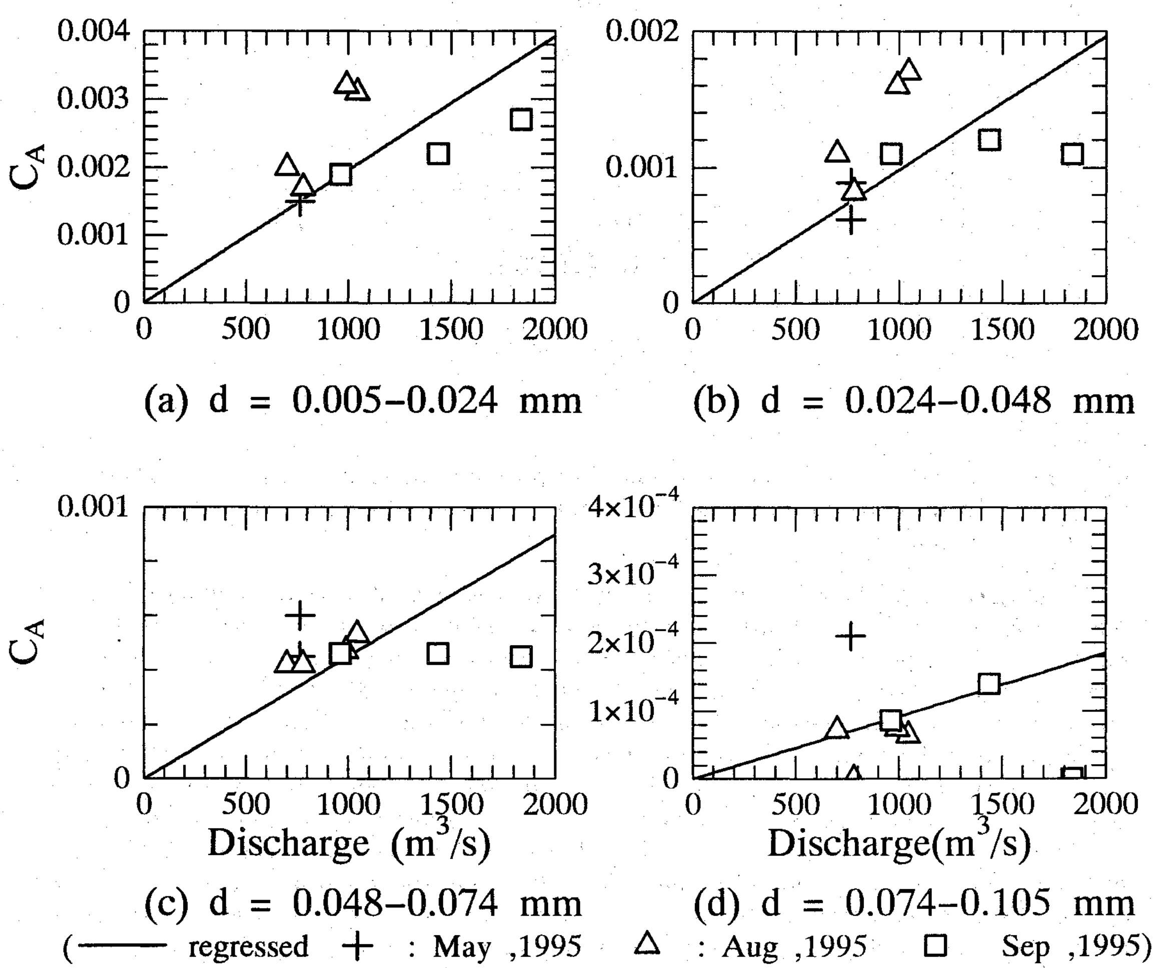

Figure 11. Relation between reference concentrations and discharges for each grain size range.

6. Conclusions

From the observations at the Abukuma River mouth and the analyses, we get following conclusions:

(1)The sampler shown here is mobile and effective to take out the information on the fine grains from flood flows.

(2)The vertical distribution of the sediment concentration is close to Rouse's solution.

(3)From the comparison of fine grains in suspension with the bed materials during the flood, there found close relation for the finer grains $d < 0.1$ mm.

(4)The reference concentrations near the bottom are related with the discharges for each grain size with some bias for each floods.

Above characteristics on the sediment at the Abukuma River mouth give boundary conditions representing the catchment 5400km^2 in considering the environment of the sea region. Especially the information on the fine grains is important because they can widely diffuse there.

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