CHAPTER 176

Grain-size Distribution of Suspended Sediments

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ABSTRACT

Field observations on the grain size distribution of suspended sediment in a surf zone has been carried out at Fukiage beach in 1990 and 1991. In these observations, a suction pump has been used to sample a sufficient amount of suspended sediment for grain size analysis. The instrument designed for the data collection worked well. Vertical distributions of sediment concentration for several grain sizes which compose suspended sediment are obtained. This enable us to do numerical simulations of beach evolution taking the composite character of suspended sediments into consideration. Results are compared with the ones obtained by conventional simulation method which assumes single grain size composition of beach materials, and discussed. The vertical distribution profiles of the concentration of suspended sediments are also compared with existing models and discussed.

1.Preface

The beach is composed of sedimcnt particles of various sizes and shapes. The grain size is one of the parameters that significantly affects the beach shape and evolution, i.c. the movement of bar, formation of berm, etc. Generally, the medium grain size, d_{50},used to define suspended sediment concentration.

Regarding grain size distributions of beach material across the shore, Bascom(1970) has conducted extensive grain size analysis of

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cross-shore material and proposed to use the medium grain size at the shoreline as the representative grain size of the beach. Bowen expressed the equilibrium beach profile as a function of settling velocity of sediment particle. He showed that the larger the grain size, the steeper the equilibrium beach profile. The characteristics and applications of equilibrium beach profiles, $h=Ay^{2/3}$, are discussed in detail by Dean(e.g. 1991). In his equilibrium beach profile model, A is a function of sediment diameter and later it is found that A is well predicted by settling velocity of sediment particle. Recently, Kato et al.(1991) has done an extensive analysis of sea bed material at Hazaki Observation Research Facility, HORF, in Chiba prefecture, Japan. However, it seems to be uneertain whether the grain size of the suspended material is the same as the sea bed material, and whether the suspended sediment which composes a wide range of grain sizes in nature can be represented by a single grain size assumption. Also, there is a few sediment transport models which considers the composition of sea bed material. Under river condition, there is evidence that the size of the bed load material is different from original bed material (see Fig.6 Chih Ted yang et al.1991).

Two field observations on grain size distributions of suspended material and sea bed material in a surfzone have been carried out at Fukiage beach in 1990 and 1991 respectively to study the effect of grain size distribution on beach profile changes due to wave action. For grain size distribution analysis of suspended material, it is necessary to obtain sufficient amount of suspended material. Therefore, a suction pump was used. The instrument was designed specifically for this observation and it worked well. This system will be shown in the next section. A similar idea to this suction pump was tested by Irie(1977) and Antsyferov(1983). Vertical distributions of suspended sediment concentration for several grain sizes were obtained.

2. Field observations.

Two field observations have been carried out at Fukiage beach one from 18 Oct. to 20 Oct. 1990 and the other from 9 July to 11 July 1991. This sandy beach faces East China Sea and extends 30km in north-south direction along with Satsuma peninsula, Kagoshima prefecture, Japan as shown in Fig.1. The observation base was set at Irikihama beach, however, the base position in 1991 was different from that in 1990.

To sample a sufficient amount of suspended material for sieving analysis from
each depth, it is impractical to use instantaneous sand trap such as by Kana(1978) and it is also difficult to record the grain size

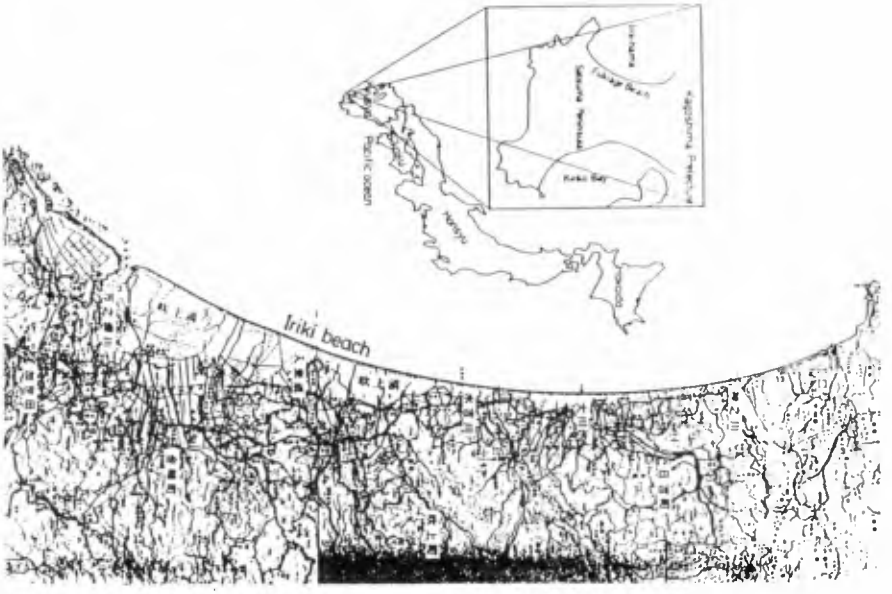


Fig. 1 Loction of Fukiage Beach

Fig.2 Measuring station (Fukiage beach)

Photo 1. Intake of suction pump

Photo 2. Installation of equipment

distribution by optical and acoustic method. To relate the grain size distribution obtained by such a bamboo trap (Fukushima et al.1955) to local wave condition cannot be achieved, because the water depth and wave condition change during the sampling time in the surfzone. Therefore, a suction pump method was designed to obtain the vertical distribution of grain size of suspended material in short period.

The intake of this suction pump under the water is shown in Photo.1 and design suction speed is faster than settling velocity of the suspended material. The speed is an order of a half meter per second, while the settling velocity of sediment is an order of several centimeters per second. The suction speed was measured before every measurement. The elevation of the intake from the sea bed is adjusted by pulling a rope attached to the suction pipe. In fact, the intake could not be well movable vertically due to the friction of the suction pipe with a sheath and misdesign of a pulley, so that a diver adjusted the elevation of the intake in the first observation. In the second observation, the position of the pulley was adjusted to the upward to avoid being buried into the sea bed and the suction pipe was modified to make less friction with the sheath.

The measuring station is shown in Fig.2. The measuring station was located in the surf zone during high water only. The working area was about 5.4m high from the sea bottom and has a surface dimension of 1.8m by 1.8m. Four capacitance type wave gauges and four pressure type wave gauges were installed between the measuring station and the shoreline. One capacitance type wave gauge is located alongshore the suction pump to relate the local wave conditions to the suspended sediment concentration. The installation of the equipment are shown in Photo.2.

The waves during two observations were relatively low and breakers were of spilling type. The wave condition of the third measurement in the first observation in 1990 is shown in Table 1.

Table 1. Wave conditions

Wave Height		Wave period	
H_{max}	33.7 cm	T_{max}	6.2 sec
$H_{1/10}$	23.0 cm	$T_{1/10}$	6.3 sec
$H_{1/3}$	18.3 cm	$T_{1/3}$	5.6 sec
H_{mean}	11.4 cm	T_{mean}	4.0 sec

The beach profiles were measured during low tide just before the measurement. Longshore bar was formed 150m offshore as shown in Fig.3. The cross shore samples of sea bed material were taken at 10m intervals.

The suspended sediment samples were taken at 5cm, 10cm, 15cm, 30cm from the sea bed in the first observation, and at 1cm, 5cm, 10cm, 20cm, 30cm, 50cm in the second observation. It took nearly 1 to 15 minutes to obtain the samples by suction pump depending on the height from the sea bed, generally speaking, the higher the suction point, the longer the suction duration due to reduced suspended sediment concentration. The suction pump was also used in the upper portion of the water column near the water surface, but was unable to collect a sufficient amount of material for the analysis.

The measurements were taken 4 times for the first observation in 1990 and three times for the second observation in 1991. In this paper, the third and the fourth measurements in the first observation are discussed. The third and the fourth measurements were carried out on 19 Oct. 1990. Sieving analyses was carried out to obtain the concentration profiles of several grain sizes of the suspended sediment. In addition, one direct sample used 2000cc polyethylene bottles has been taken by diver during the first observation.

3. Data analysis

Data set of grain size distribution of sea bed materials, grain size distribution of suspended materials, the concentration of several grain sizes which compose suspended sediment and total concentration have been taken.

3.1 Grain size distribution

Grain size distributions of suspended material obtained at several depths were sieved, first. In addition, grain size distribution of sea bed material at the measuring station was also obtained to compare with the composition of suspended materials. The grain size distribution from the third measurement is shown in Fig.4(a). The composition of suspended material is smaller than the original sea bed material. As can be seen Fig.4(b), the representative grain size of the bed material does not directly correspond to that of the suspended material in a calm wave condition. Unfortunately, data under severe wave condition is not available.

It is reassured that small waves of short periods do not cause

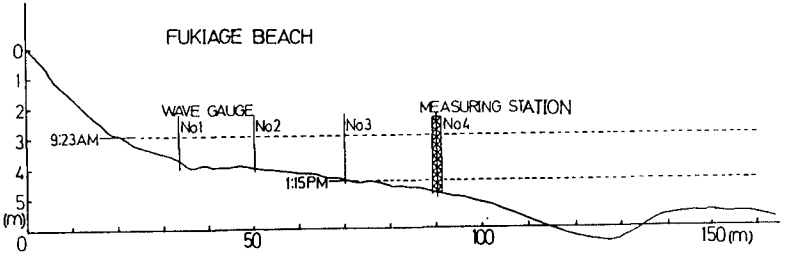
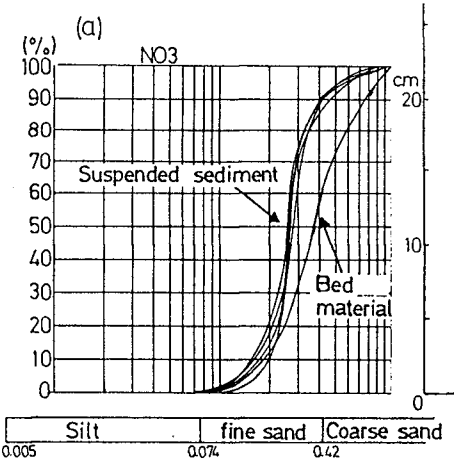


Fig.3 Beach profile



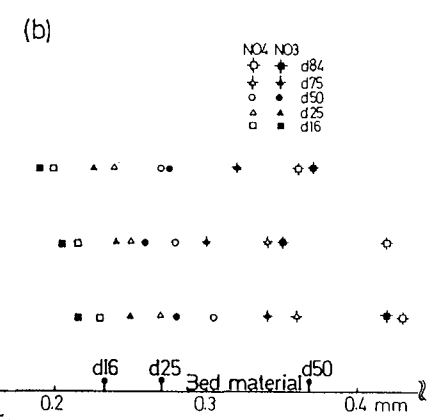


Fig. 4 (a) Grain size distribution of sea bed material and suspended sediment

(b) Representative grain sizes of sea bed material and suspended sediment

suspension of the entire original bed material, but only cause suspension of finer sea bed material. Under this condition, the composition of suspended materials are smaller than that of the sea bed material.

3.2 Suspended sediment concentration of several grain sizes

The concentrations of several grain sizes are obtained. The results are shown in Fig.5, where, the value of each grain size shown represents the average size of sieve size. The 0.34 mm material which is close to the mean grain size(d_{50}) of the sea bed material contributes nearly 50% of the suspended material at 5cm from the sea bed level. The 0.18mm, 0.63mm, 0.09mm material contribute, in respective orders, lesser amount. This order of contributions also holds in the upper layer in the third measurement.

The vertical distribution of concentration at each grain size is assumed to follow an exponential form as shown by eq.(1) (due to Dally et al. 1980).

$$C(z) = C_a \cdot \exp\{F(z-z_a)\} \tag{1}$$

while,

$$F = \frac{-15W}{h}\sqrt{(\tau/\rho)} \tag{2}$$

where, C(z) is the suspended sediment concentration at depth(z), Ca is the concentration at the reference level (z_a), z is a height from the sea bed, h is a water depth and $\sqrt{(\tau/\rho)}$ is a shear velocity. The shear velocity $\sqrt{(\tau/\rho)}$, is computed by two different methods Noda(1968) and Dally(1980); They are :

$$\sqrt{(\tau/\rho)} = \sqrt{2\pi\nu/T} \cdot \frac{\pi H}{\tanh(kh)} \tag{3}$$

$$\sqrt{(\tau/\rho)} = (fH^2g/16h)^{0.5} \tag{4}$$

where ρ is the density of water, T is the wave period, H is the wave height and ν is the coefficient of kinematic viscosity set to be equal to 0.01 cm^2/sec (20 c) in this case.

The concentrations calculated by eq.(4) are also shown in Fig.5. These concentration curves fit quite well to the data in the lower position

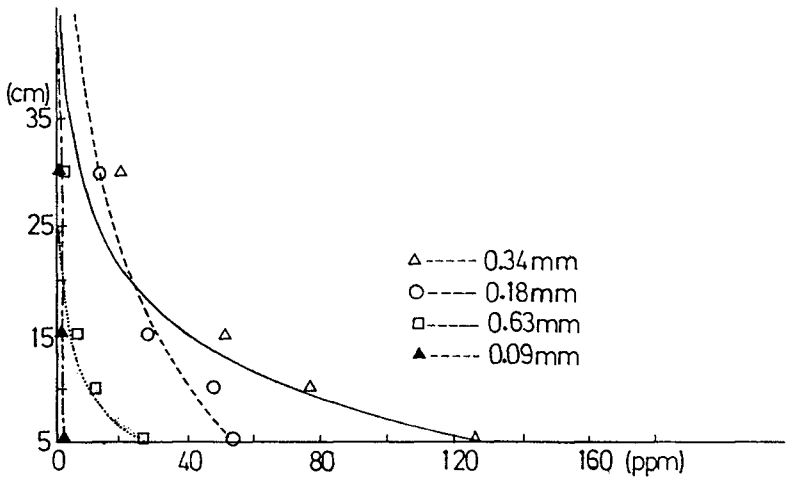


Fig. 5 Suspended sediment concentration of individual grain sizes based on Dally's shear velocity eq.(4)

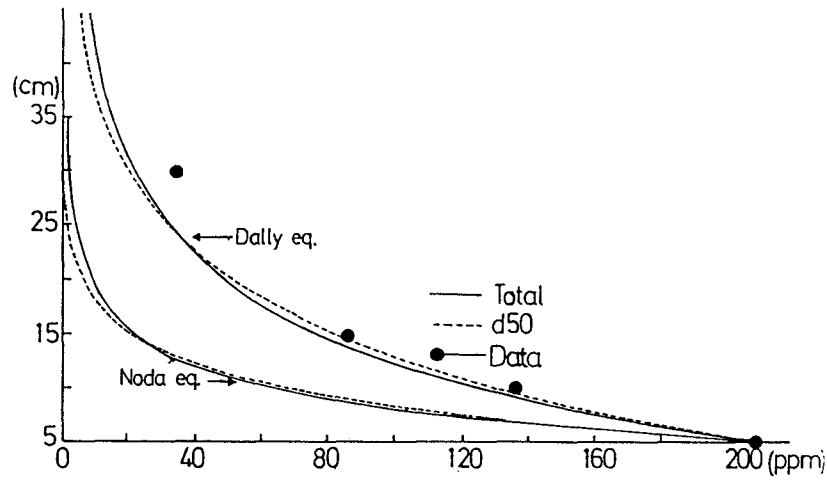


Fig. 6 Total concentration of suspended sediment

(i.e., 5cm, 10cm, 15cm), but there is disagreement between the exponential curve and the data in the upper position(z=30cm) for the case of 0.34mm. Combining the calculations of suspended sediment concentrations for several grain sizes, the total concentration of suspended sediment is calculated and is compared to the field data. This total concentration is defined as the sum of concentrations of individual grain sizes, i.e.,

$$C_{total}(Z) = \sum_{i=1}^{N} C_{ai} \cdot \exp\{F_i(Z-Z_a)\} \qquad (5)$$

where, the subscript i refers to the ith grain size. The total concentration based on
the mean grain size(d_{50}) is also calculated, shown as dotted line in Fig.6. The data from the third measurement is also shown in the figure as black circles. It is seen that the concentration calculated by eq.(5) is slightly smaller than that derived from d_{50} in lower regime, and is higher in the upper regime. However, their difference is small. This might be due to the fact that the waves were small in this measurement, only in the order of 20cm. For large waves, their difference could become larger.

4. Numerical simulation of beach evolution.

In this section, simple numerical simulations of beach evolution were carried out to illustrate the effect of the composite of sea bed materials by comparing the results with the ones obtained by a conventional approach which assume single grain size(d_{50}) composition of beach material. Two types of beach profile storm and normal profiles, or bar and berm profiles are used.

The composite characters of sea bed materials used for numerical simulation are shown in Fig.7. Case 1 assumes that the beach is composed of single size grain which is represented by mean grain size(d_{50}) set to be 0.2mm. The mean grain sizes of case 2 and 3 are also 0.2mm, but the sorting coefficient of two cases are chosen to be 1.47 and 2.40 respectively; thus the beach is composed of composite sand size. Case 4 assumes a single grain size composition of beach material with mean grain size equal to 0.6mm. The mean grain size of case 5 and 6 are also 0.6mm, but again the sorting coefficients are chosen to be 1.45 and 2.36 respectively.

4.1 Basic equation

The conventional beach evolution model proposed by Dally is applied

to the numerical simulation by taking into consideration the composite characteristics of the bed material. The suspended sediment transport is written as:

$$Q_{sg} = \int_{-h}^{0} u(z) \cdot c(z)\, dz \tag{6}$$

where, u(z) is a mean horizontal velocity of sediment particles which consists of components; an oscillatory component due to waves, and velocity component due to mean flow, c(z) is a concentration profile as expressed in eq.(1). To calculate the suspended sediment transport rate, the water column is divided into two layers; one is the inner layer lower than DF(=wT) and the other is the outer layer higher than DF, where, w is the settling velocity. This settling velocity is obtained by Rubey's law.

$$W = \sqrt{\frac{2(\rho_s - \rho)}{3\rho} gd + \frac{36\nu^2}{d^2}} - \frac{6\nu}{d} \tag{7}$$

where, ρ_s is the density of sediment particle, g is the gravitational acceleration and d is the diameter of sediment particle.

The calculated total suspended sediment transport rate is applied to the continuity equation given below to obtain the new beach profile.

$$\frac{dh}{dt} = \frac{1}{1-\lambda} \frac{dQ}{dx} \tag{8}$$

This new beach profile is used to revise the input wave condition for the next time step.

The effect of sorting sea bed material due to waves and the silt component of bed material are excluded in the computation.

4.2 Numerical results

The numerical results of beach evolution for 0.2mm mean grain size material and 0.6mm mean grain size material are shown in Fig.8 and Fig.9, respectively.

Based upon a fall veloeity criterion proposed by Dean, the wave and sediment condition are expected to produce the storm profiles which are bar formation as shown in Fig.8 and normal profiles which are berm formation as shown in Fig.9. It appears that the size of the bar feature

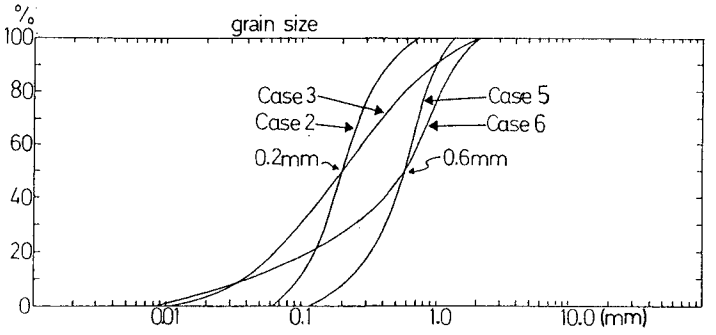


Fig. 7 Composion of bed materials for numerical simulation

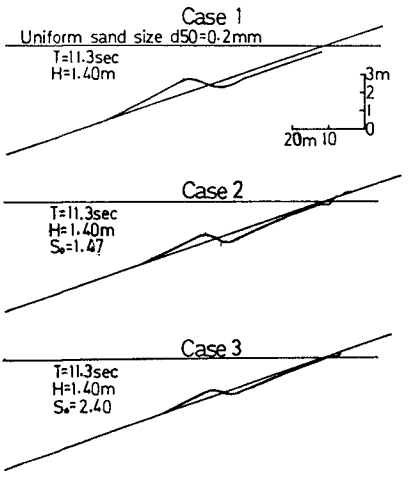


Fig. 8 Numerical simulation for bar profile after 200sec

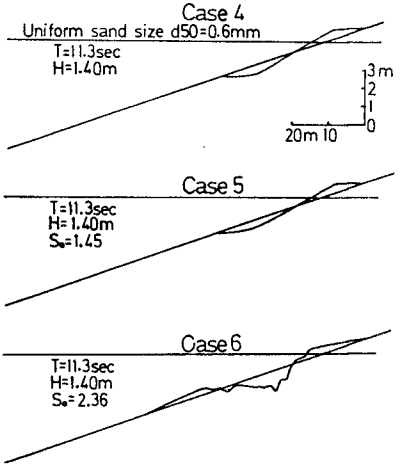


Fig. 9 Numerical simulation for berm profile(200sec)

diminish with the increasing of the range of the material size in Fig.8. The position of bar crest is also located slightly shoreward for this wave condition. For the storm profile, the composite beach material appears to have a smoothing effect and the bar formation becomes lower and wider as the range of the sand size increase. For the normal profiles shown in Fig.9, it appears that the closure depth increases with the increasing of the range of the sand size. The cross shore sand transport for case 4 and 5 are onshore sediment transport while that for case 6 is consisted of onshore and offshore sediment transports to cause a different type of beach profile for this wave condition.

Generally, the results for storm and normal profiles based on a single grain size assumption are similar to these profiles produced by a narrow range of beach material, while the profiles are different from the beach profiles produced by a wide range of sea bed material.

5. Concluding remarks

The conclusions are ;

(1) The pumping system designed to obtain the suspended materials for grain size analysis worked well in the lower portion of the water column. In the upper portion of the water column, the data could not collect in this measurement, since the reduction of suspended sediment concentration.

(2) The representative grain size of the suspended materials decreases with increasing elevation. The mean grain size of the suspended material is smaller than that of original sea bed material.

(3) Concentration profiles of individual grain size can be represented by the widely accepted exponential equation.

(4) The total concentration defined as the sum of the individual grain size concentrations underestimates in the lower portion of the water column and overestimates in the upper region of the water column with reference to the concentration profile derived from single grain size assumption.

(5) Numerical simulations of beach profile evolution taking into account the composite nature of the suspended material have been carried out for erosional and normal profiles. The results are different from the ones with the conventional approach of using a single grain size. For bar profile, the composite beach material appears to have a smoothing effect. So the bar formation becomes lower and wider as the range of sand size increases. For the berm formation, the profile change of composite beach material becomes also wider as the range of sand size increases.

We hope that the further observations under the severe wave

condition will provide additional information about the effect of the composition of sea bed material on beach profile evolution.

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