# CHAPTER NINETY ONE

## CALCULATION OF THE RATE OF NET ON-OFFSHORE SEDIMENT TRANSPORT ON THE BASIS OF FLUX CONCEPT


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Abstract

Time and spatial variations of sediment concentration of both hed load and suspended load in the process of two-dimensional beach deformation were investigated experimentally. At the same time, the relation between the velocities of water-particle and sediment migration was analyzed theoretically. By using those results, a net rate of on-offshore sediment transport in the process of two-dimensional model beach deformation $\overline{q}_f$ was calculated on the basis of sediment flux. It is found that $\overline{q}_f$ coincides fairly well with the net rate of on-offshore sediment transport calculated from the change of water depth.


### 1. Introduction

The rate of sediment transport has been formulated in various ways and a variety of formulas have been proposed. Some of them deal with only bed load (Einstein(1972), Madsen et al.(1976)) and others are formulated by assuming that the most of sediment is transported in suspension (Bakker(1974), Nielsen et al.(1978), Kana et al.(1977)).

Generally, sediment is brought into suspension from the bed load layer by wave action and the bed load layer plays a role as a boundary condition for the suspended load. Therefore, bed load can exist but suspended load can not exist by itself. On the basis of this fact, some formulas to estimate the rate of suspended sediment transport are proposed by relating bed load to suspended load(Bijker(1971),Walton(1979)).

However, in most of the previous studies, the time averaged rate of sediment transport over one or one-half wave cycle is directly delt with and only in a few studies (Bakker(1974), Nielsen et al.(1978)), phase variations of the rate of sediment transport are taken into account.

Further, bed load and suspended load differ in the speed of migration and sediment concentration each other. In a two-dimensional beach deformation process, it is also said that the directions of sediment transport in bed load and suspended load do not always coincide. Consequently, two different expressions have been prepared to estimate the rates of bed load and suspended load.

The rate of sediment transport $q(t)$ is universally expressed by using the sediment flux as a function of the phase as follow:

$$q(t) = \int_{-(h+\delta)}^{\eta(t)} C(z,t)\mathbf{U}_s(z,t)dz \quad (1)$$

where $C(z,t)$ is the volumetric concentration of sediment, $\mathbf{U}_s(z,t)$ is the velocity vector of sediment migration, $\eta(t)$ is the surface elevation, h is the water depth defined as the distance from the still water level to the upper bed load layer and $\delta$ is the thickness of the bed load layer. So, $h+\delta$ is the depth where no sediment movement takes place. z-axis is taken upward from the still water level as shown in Fig.1.

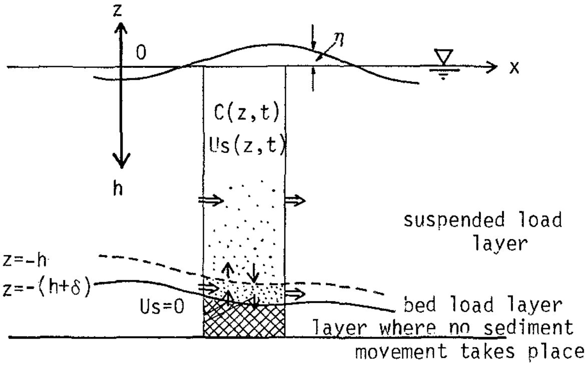


Fig.1 Definition sketch

The aim of this study is to estimate the on-offshore sediment transport rate including both bed load and suspended load according to Eq.(1) systematically. To calculate $q(t)$ from Eq.(1), it is necessary to estimate time and spatial variations of sediment concentration of both bed load and suspended load as well as the migration speed of sediment.

The authors, first, investigated the characteristics of bed load and suspended load concentration by measuring them in two-dimensional model beach experiments. Then, the relation between water-particle velocity and speed of sediment migration was investigated by analyzing the motion of sediment particle at various sediment concentration. Finally, the net rate of on-offshore sediment transport was calculated on the basis of Eq.(1) by using the measured sediment concentration and analyzed speed of sediment. The results are discussed by comparing with the on-offshore sediment transport rate calculated from the change of water depth.

## 2. Characteristics of time and spatial variation of sediment concentration

### 2.1 Previous works

A lot of studies on the suspended sediment have been conducted. Their objectives are to determine the vertical profile of time averaged suspended sediment concentration by applying an one-dimensional diffusion theory, that is, to determine the so-called height of reference level, concentration at the reference level and a diffusion coefficient $\varepsilon_z$. Some attempts have been made to simulate the phase variation of suspended sediment concentration by assuming the constant $\varepsilon_z$ and the phase dependent concentration at the reference level (Bakker(1974), Nielsen et al. (1978)).

As for the concentration of bed load, only the experimental results measured by Horikawa et al.(1982) are reported. However, at present, it is impossible to quantitatively estimate the time variation of sediment concentration of both bed load and suspended load.

### 2.2. Measurement of sediment concentration of both bed load and suspended load

A resistance type sediment concentration measuring system devised by Horikawa et al.(1982)(see Fig.2) was used to measure sediment concentration of bed load and suspended load.

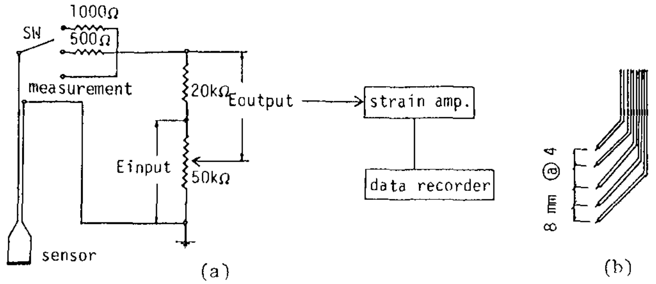


Fig.2 Resistance type sediment concentration measuring system

This system, first, measures the difference of electric resistance between clear water and sediment laden water and then transfers it to the concentration by using a calibration curve. The sensor was made of two enamel coated wires of 5cm long and 0.3mm diameter. Five sensors fixed vertically at a distance of 8mm were used to measure sediment concentration at five different levels simultaneously as shown in Fig.2(b).

Sediment concentration C(z,t) was measured in four different types of beach deformation processes as shown in Table 1 together with the experimental conditions. In Table 1, $H_0$ is the deep water wave height, T is tha wave period, i is the initial beach slope and d is the mean grain size of the bed material. Concentration measuring points covered whole littoral zone and were distributed vertically from the bed load layer and suspended load region.

Table 1
Two-dimensional model beach experiments and their experimental conditions

| | $H_0$(cm) | T(s) | i | d(cm) | deformation types |
|---|---|---|---|---|---|
| Case 1 | 11 | 1.20 | 1/10 | 0.02 | erosion type |
| Case 2 | 11 | 1.28 | 1/20 | 0.02 | transition type |
| Case 3 | 18 | 1.28 | 1/20 | 0.05 | transition type |
| Case 4 | 12 | 1.28 | 1/20 | 0.05 | acretion type |

From measured sediment concentration C(z,t), time averaged concentration $\overline{C}(z)$ and phase averaged concentration $C_p(z,t)$ over 60 waves were calculated. Beach profiles and wave heights were also measured at definite time intervals.

2.3. Time variations of sediment concentration

Fig.3 shows examples of measured sediment concentration C(z,t) in the erosion type beach deformation. In Fig.3(a), measured beach profiles and 6 concentration measuring points (s-1 to s-6) are shown. Fig.3(b) is a result measured at s-4 (inside wave breaking point) and Fig.3(c) is a result obtained at a ripple crest (s-2) in the offshore region. Fig.(i) in each figure shows the surface elevation, Fig.(ii) indicates the concentration in the bed load layer($z^* \leq 0$) and Figs.(iii) and (iv) are the suspended sediment concentration at different heights($z^* \geq 0$) where $z^*$ is measured upward from the bottom surface.

It can be seen from these figures that the concentration in the bed load layer in both the surfzone(Fig.3(b)(ii)) and the offshore region(Fig.3(c)(ii)) decreases when a wave crest passes and this indicates that at this phase, an intense sediment transport takes place in the bed load layer. Suspended sediment concentration near the bottom in the surfzone(fig.3(b)(iii)) increases corresponding to the decrease of concentration in the bed load layer and has one peak during one wave cycle. However, in the upper region(Fig.3(b)(iv)), concentration of suspended sediment no longer shows any correspondence with the surface elevation. While in the offshore region(Figs.3(c)(iii) and (iv)), concentration of suspended sediment has two apparent peaks during one wave cycle and this coincides with the results measured by Nakato et al.(1977) and others on a horizontal bottom with bed formations.

On the other hand, as can be seen from Figs.3(c)(iii) and (iv), the maximum concentration of suspended sediment appears almost at the same time without phase lag regardless of the height from the bottom. This indicates that the diffusion of suspended sediment takes place not only in the vertical direction but also in the horizontal direction. Therefore, one-dimensional diffusion theory can not apply to estimate the time variation of suspended sediment concentration. The authors analyzed time variations of suspended sediment concentration by assuming that suspended sediment diffuses from an instanteneous point source according to Ornstein-Uhrenbeck process with constant $\varepsilon_z$(Soong(1973)). It is found that the procedure gives a good prediction of the time variation of suspended sediment concentration provided that the water-particle velocity due to waves is known.

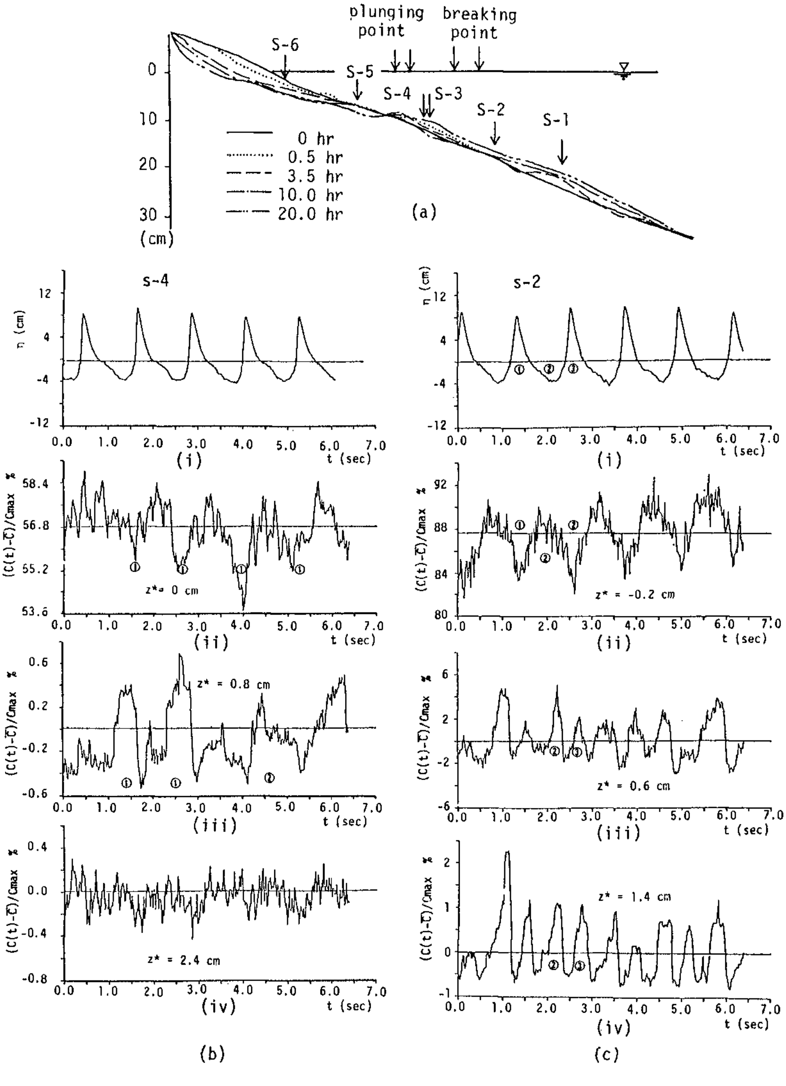


Fig.3 Time variation of sediment concentration
(erosion type beach deformation)

2.4. Vertical distribution of time-averaged sediment concentration

For reference, some examples of vertical distributions of time-averaged concentration of sediment $\overline{C}(z^*)$ measured in the erosion type beach deformation process are shown in Fig.4.

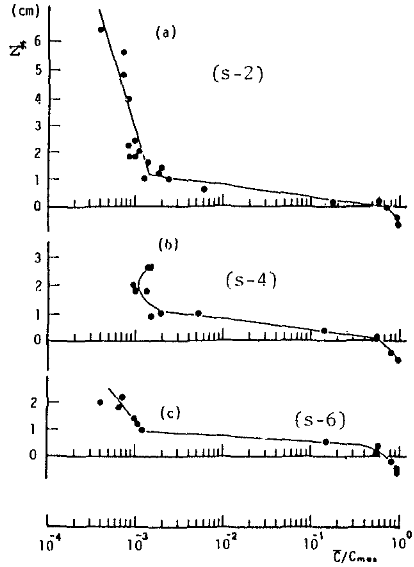


Fig.4 Vertical distribution of time averaged sediment concentration (erosion type beach deformation)

Fig.4(a) is the result obtained in the offshore region s-2(corresponding to Fig.3(c)) showing that $log\overline{C}$ is proportional to $z^*$. Fig.4(b) is the result measured near the wave breaking point s-4(corresponding to Fig.3(b)) and shows that $log\overline{C}$ is not directly proportional to $z^*$, that is, the concentration near the water surface is larger than that in the middle of water depth. This kind of $\overline{C}$-distribution have also been measured by Kana et al.(1977) in the field under plunging wave breaking. $\overline{C}$-distribution in Fig.4(c) was measured in the nearshore zone s-6 where the strong turbulence brought by plunging waves already attenuated. In this region, $log\overline{C}$ again becomes proportional to $z^*$.

From these figures together with the results measured in the other beach deformation processes, it is found that for the vertical distribution of time averaged suspended sediment concentration, one-dimensional diffusion theory with constant $\varepsilon_z$ is applied in appearence except for the region near the wave breaking point.

3. Relation between the migration speed of sediment and water-particle velocity

The motion of the particle suspended in a fluid is usually analyzed by Lagrangian method (Hinze(1959)). Namely, the linearized equation which subjects the motion of the particle in a fluid is expressed by

$$\frac{d\mathbb{U}_s}{dt} + B\mathbb{U}_s = B\mathbb{U}_f + A\frac{d\mathbb{U}_f}{dt} + \mathbb{C} \qquad (2)$$

$$A=3\rho/(2\rho_s+\rho),\quad B=36\mu/((2\rho_s+\rho)d^2),\quad \mathbb{C}=(0,0,-2(\rho_s-\rho)g/(2\rho_s+\rho))$$

where $\rho$ and $\rho_s$ are the densities of fluid and particle, d is the diameter of particle, $\mu$ is the fluid viscosity, g is the gravitational acceleration and $\mathbb{U}_s$ and $\mathbb{U}_f$ are the velocities of suspended particle and water particle. When the fluid motion is purely oscillatory in the direction of x-axis,ie, $\mathbb{U}_f=(\widehat{U_{fo}}\exp(-i\sigma t),0,0)$, the solution which satisfies an initial condition at $t=0, U_s=0$ becomes

$$U_s = \widehat{U_{fo}}G^{1/2}\,(\cos(\sigma t+\theta) - \exp(-Bt)\cos\theta) \qquad (3)$$

$$G=(A^2\sigma^2+B^2)/(\sigma^2+B^2),\quad \theta=\tan^{-1}((B\sigma(1-A)/(A\sigma^2+B^2))$$

where $\sigma=2\pi/T$.

Figs.5 and 6 show the amplitude ratio of water-particle velocity and the velocity of suspended particle $\widehat{U_s}/\widehat{U_{fo}}$ and the phase shift $\theta$ as a function of the diameter of particle d.

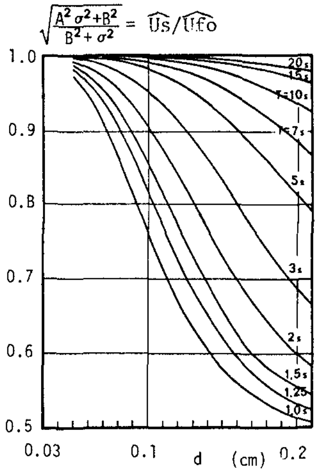


Fig.5 Relation between $\widehat{U_s}/\widehat{U_{fo}}$ and d

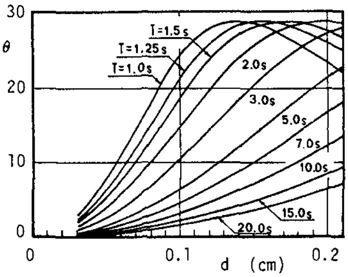


Fig.6 Relation between θ and d

From these figures, it is found that $\widehat{U_s}/\widehat{U_{fo}} \fallingdotseq 1$ and $\theta \fallingdotseq 0$ for the particle which is usually seen in suspension in the laboratory experiments($d \leq 0.5$mm). So, the velocity of suspended sediment $U_s$ is approximated by water-particle velocity $U_f$.

The same procedure can apply to the motion of a projected particle on the bottom (Eagleson et al.(1958)). However, the motion of bed load in a region where an intense sediment transport in high concentration takes place can not be analyzed by this method. Therefore, the authors analyzed the motion of bed load sediment in such regions by solving a boundary layer equation in the Eulerian system of coordinates shown in Fig.7 under the following assumptions:

1) the bed load layer is a Newtonian fluid with a hypothetical viscosity $\mu_s$,
2) the flow on the bottom is a laminor, for simplicity,
3) the bottom sediment layer is moved by the boundary shear and the pressure in the bottom sediment layer.

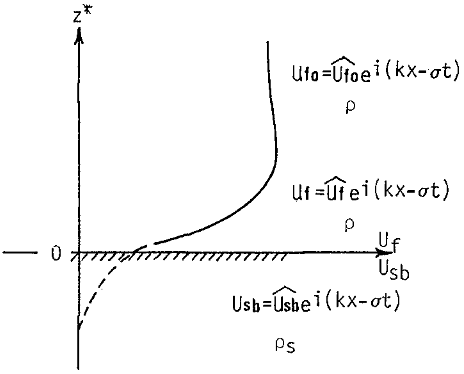


Fig.7 Definition sketch of the coordinates

According to Bagnold(1956), the first assumption is true when the concentration of the bottom sediment Cb is less than 0.53. Then, the equation of motion for $z^*=\infty$ (main flow), $z^*\geq 0$ (flow within the boundary layer) and $z^*\leq 0$ (sediment motion in the bed load layer) are expressed as follows:

$$\frac{\partial U_{fo}}{\partial t} = -\frac{1}{\rho}\left(\frac{\partial p}{\partial x}\right) \qquad z^*=\infty$$

$$\frac{\partial U_f}{\partial t} = -\frac{1}{\rho}\left(\frac{\partial p}{\partial x}\right) + \frac{\mu}{\rho}\left(\frac{\partial^2 U_f}{\partial z^{*2}}\right) \qquad z^*\geq 0 \qquad (4)$$

$$\frac{\partial U_{sb}}{\partial t} = -\frac{1}{\rho_s'}\left(\frac{\partial p_s}{\partial x}\right) + \frac{\mu_s}{\rho_s'}\left(\frac{\partial^2 U_{sb}}{\partial z^{*2}}\right) \qquad z^*\leq 0$$

where $\rho_s'=(1-C_b)+\rho_s C_b$ is the density of the bottom sediment layer, p and $p_s$ are the pressures in water and the bottom sediment layer and $U_{sb}$ is the velocity of the bottom sediment layer.

For the pressure $p_s$ in the bottom sediment layer, the following expression proposed by Sleath(1978) is used:

$$p_s = p_o\frac{\cosh(k(\kappa x/\kappa z)(z^*+\delta b'))}{\cosh(k(\kappa x/\kappa z)\delta b')}\exp(i(kx-\sigma t)) \qquad (5)$$

$$p_o = \rho g H/(2\cosh kh)$$

where k is the wave number, $\kappa x$ and $\kappa z$ are the coefficients of premeabirity of the bottom sediment layer in x and z directions, $\delta_b'$ is the thickness of the bottom sediment layer and H is the wave height at the water depth h.

For $\mu_s$ in Eq.(4), the authors use the following relation proposed by Eilers(1941):

$$\mu_s/\mu = (1 + (2.5C_b/2(1-1.35C_b)))^2 \qquad (6)$$

It is said that this relation remains varid for the wide range of $C_b$.

Boundary conditions are given as follows:

$$\text{at } z^* = \infty \qquad U_f = U_{fo} = \widehat{U_{fo}} \exp(i(kx - \sigma t))$$
$$\text{at } z^* = 0 \qquad U_f = U_{sb} \text{ and } \mu(\partial U_f/\partial z^*) = \mu_s(\partial U_{sb}/\partial z^*) \qquad (7)$$
$$\text{at } z^* = -\delta_b \qquad U_{sb} = 0$$

$\delta_b$ in Eq.(7) is the thichness of the bed load layer and is determined as the largest integer $\delta_b/d$,ie, the number of the bed load layer which satisfies the following inequarity:

$$\mu_s(\partial U_{sb}/\partial z^*) \geq d(\rho_s - \rho) g C_b \tan\phi \; (\delta_b/d) \qquad (8)$$

where $\phi$ is the angle of repose of the bed material in water.

In the calculation, at first, $\delta_b$ was assumed to be $\delta_b'$ as a first approximation and the calculations were repeated untill the boundary condition Eq.(7) and Eq.(8) were satisfied.

Fig.8 shows an example of calculated vertical distribution of $U_{sb}$ as a function of the phase. The calculated conditions are also shown in the figure. The vertical distribution of the water-particle velocity obtained from an ordinally laminor boundary layer equation under the boundary condition that at $z^*=0$, $U_f=0$, that is,

$$U_f = \widehat{U_{fo}}(\cos\sigma t - \exp(-\beta z^*)\cos(\sigma t - \beta z^*)) \qquad (9)$$
$$\beta = \sqrt{\sigma/2\nu}$$

is also shown in the figure by dotted lines where $\nu=\mu/\rho$.

By comparing these two vertical profiles, it is found that the effect of the moving boundary remains in a so-called boundary layer ($z^* = \sqrt{\nu T/\pi} \fallingdotseq 0.2$mm). Further, the thickness of the bed load layer is also found to change within one wave cycle and it becomes only 1mm, in other wards, only 3 layers move as a bed load at the maximum in the case shown in Fig.8.

Fig.9 shows the relation between the amplitude ratio $\widehat{U_{sb}}/\widehat{U_{fo}}$ at the bottom surface($z^*=0$) and sediment concentration Cb. As can be seen from this figure, $\widehat{U_{sb}}/\widehat{U_{fo}}$ decreases with increasing Cb and with decreasing Reynolds' number Re($=\widehat{U_{fo}}^2T/\nu$). However, in the region where Re is larger than $25\times10^4$, the increase of $\widehat{U_{sb}}/\widehat{U_{fo}}$ with increasing Re becomes less significant.

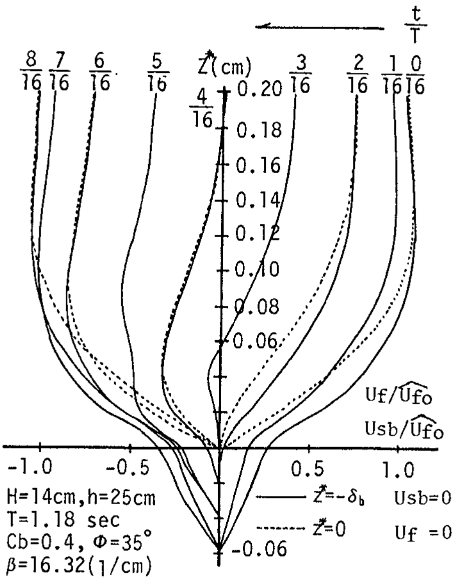


Fig.8 Vertical distribution of Usb/Ufo and Uf/Ufo

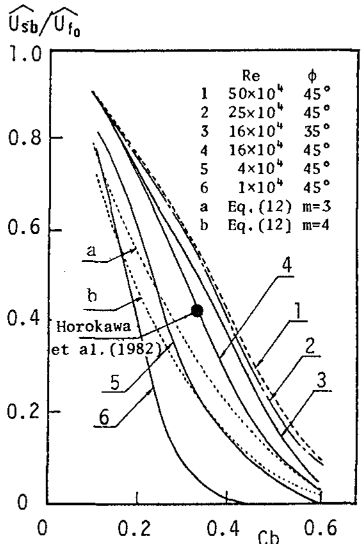


Fig.9 Relation between $\widehat{Usb}/\widehat{Ufo}$ and d

An experimental result measured by Horikawa et al.(1982) under the sheet flow condition caused by the oscillatory flow is also shown in the figure. Although this value can not be directly compared with the calculated values, calculated results are judged to give a little larger value of $\widehat{Usb}/\widehat{Ufo}$ than the measured one when compared at the same Re and Cb.

However, the procedure to relate $\widehat{Usb}/\widehat{Ufo}$ to Cb mentioned above is little bit complicated to use in Eq.(1). Therefore, the authors tried to simplify this process. Bagnold(1956) derived the following relation between the drag coefficient f' of the sediment laden flow and sediment concentration Cb:

$$f'/f \propto (1 - Cb)^{-m} \quad , \quad m = 3 \text{ to } 4 \tag{10}$$

where f is the drag coefficient in the clear water defined by

$$f = \tau/(\rho\, Uf^2/2) \tag{11}$$

and $\tau$ is the drag force acting on a particle and Uf is the velocity of the unidirectional flow. By using this relation, the ratio of the velocity of the particle in flow Us and Uf can be expressed in term of only Cb as follow:

$$Us/Uf = (1 - Cb)^{m/2} \tag{12}$$

However, in general, no sediment movement takes place when all particles in the bed layer are in static contact. Cb in the bed layer in this state corresponds to Cb=Cmax=0.74 for uniform spheres perfectly piled. Therefore, it seems reasonable to replace Cb in Eq.(12) with Cb/Cmax as

$$Us/Uf = (1 - Cb/Cmax)^{m/2} \tag{13}$$

Assuming that this relation holds in the case of sediment movement by waves, Us/Uf calculated from Eq.(13) are also shown in Fig.9 for m=3 and 4 by dotting lines. By comparing these with the results obtained from Eqs.(4) to (8), it is found that m in Eq.(13) depends on Re and m=3 and 4 correspond to $Re=16\times10^4$ and $4\times10^4$ in the region where Cb is larger than 0.4.Therefore, in the calculation of Eq.(1), Eq.(13) is used as an approximation of Eqs.(4) to (8).

## 4. Calculation of the net rate of on-offshore sediment transport

### 4.1. Vertical distribution of the net sediment flux

In this section, the net rate of on-offshore sediment trasnport in four kinds of beach deformation processes(see Table 1) are calculated by using Eq.(1). In advance of the calculation of Eq.(1), the time averaged rate of local on-offshore sediment flux $\overline{q}f(z^*)$ defined by

$$\overline{q}f(z^*) = \overline{Us(z^*,t)\, C(z^*,t)} \tag{14}$$

was calculated. In this equation, Us(z,t) was estimated from Eq.(13) in which Ufo($z^*$,t) was calculated by using a linear wave theory,ie,

$$Uf\acute{o} = \sqrt{g(h+\overline{\eta})}\, \frac{\eta(t)-\overline{\eta}}{h+\overline{\eta}} \tag{15}$$

where $\overline{\eta}$ is the time averaged surface elevation and m in Eq.(13) was determined to be 4 for simplicity, although Re in the experiment ranged between $10^4$ and $5\times10^4$. Because Eqs.(4) to (8) seems to overestimate Usb/Ufo.

For $C(z^*,t)$, $\overline{C}+Cp$ calculated from the measured sediment concentration in the two-dimensional model beach experiments mentioned in § 2 within 3hrs. after waves began to incident.

Fig.10 shows some examples of the vertical distributions of $\overline{q}f(z^*)$ in the process of erosion type beach deformation. Concentration measuring points are again shown in Fig.10(a) together with beach plofiles. As can be seen from Figs.10(b) and (c), in the offshore region, net bed load flux is in the direction of wave propagation(onshore direction) and net flux of suspended sediment is in the offshore direction. This means that the net rate of on-offshore sediment transport in these region is brought about by the difference of two large quantities,ie, bed load in the onshore direction and suspended load in the opposit direction. While, in the surf zone shown in Figs.10(d),(e) and (f), both bed load and suspended load are in the offshore direction and suspended load apparently surpasses bed load.

Fig.11 shows the vertical distribution of $\overline{q}f(z^*)$ in the process of acretion type beach deformation. Beach plofiles and concentration measuring points are shown in Fig.11(a). Being different from the case shown in Fig.10, there is no significant offshore suspended sediment transport throughout the littoral zone and the maximum sediment flux appears on the bottom surface or in the bottom sediment layer. This means that in the process of acretion type beach deformation, onshore bed load transport is apparently surpasses offshore suspended sediment transport.

In the transition type beach deformations, it is found that there exist two regions, one is the region where onshore bed load transport surpasses and the other is the region where offshore suspended sediment transport surpasses.

As reported by the authors previously(Sawaragi et al.(1980)), whether bed load surpasses suspended load or not at an arbitrary point on a beach can be determined by the ratio of shear velocity $U^*$ and settling velocity of sediment in still water $w_0$. That is, in the region where $U^*/w_0$ is smaller than 1, onshore bed load transport surpasses offshore suspended load and in the region where $U^*/w_0$ is larger than 1, suspened load becomes dominant. In which, $U^*$ is defined by $\sqrt{fUfo^2/2}$ and f is estimated from Jonsson's formula(Jonsson(1980)) assuming that the roughness height is equal to the sediment dimeter d. This criterion is reconfirmed by the present experiments.

4.2 Calculation of the net rate of on-offshore sediment trasnport

Figs.12 and 13 show the comparisons of the net rate of on-offshore sediment transport $\overline{q}_f$ obtained by integrating $\overline{q}f(z^*)$ shown in Figs.10 and 11 vertically with $\overline{q}_h$ calculated from the measured change of water depth. In the integration, $\overline{q}f(z^*)$ was approximated by the dotted lines drawn in the figures.

As can be seen from these figures, $\overline{q}f$ calculated from the measured sediment concentration agrees with $q_h$ calculated from the change of water depth. Judging from these, the proposed procedure to calculate the net rate of on-offshore sediment transport provides a good estimate if only the time and spatial variations of sediment concentration and

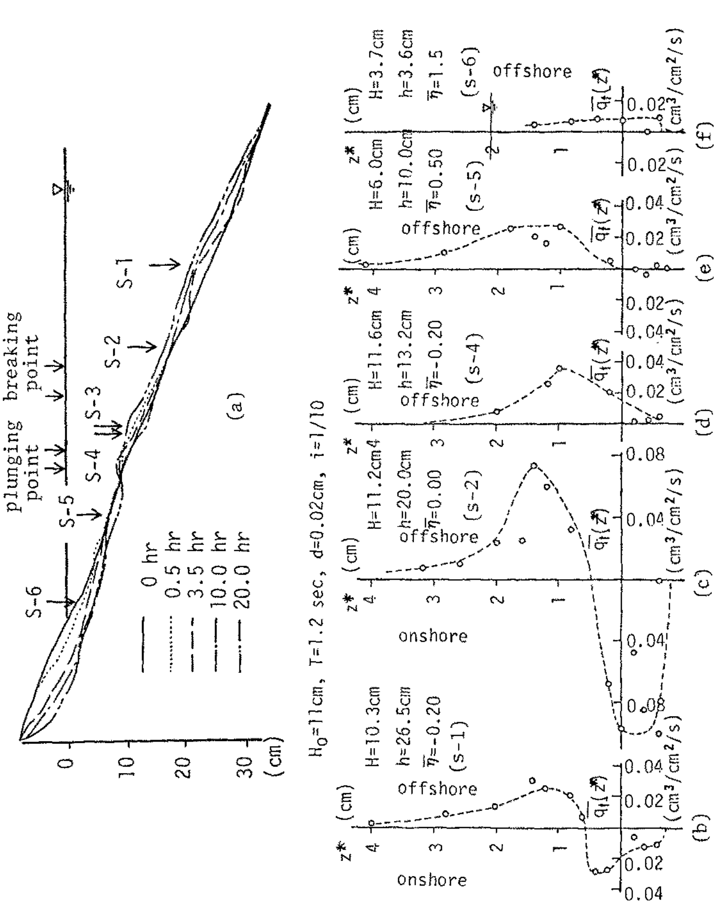


Fig.10 Vertical distribution of sediment flux (erosion type beach deformation)

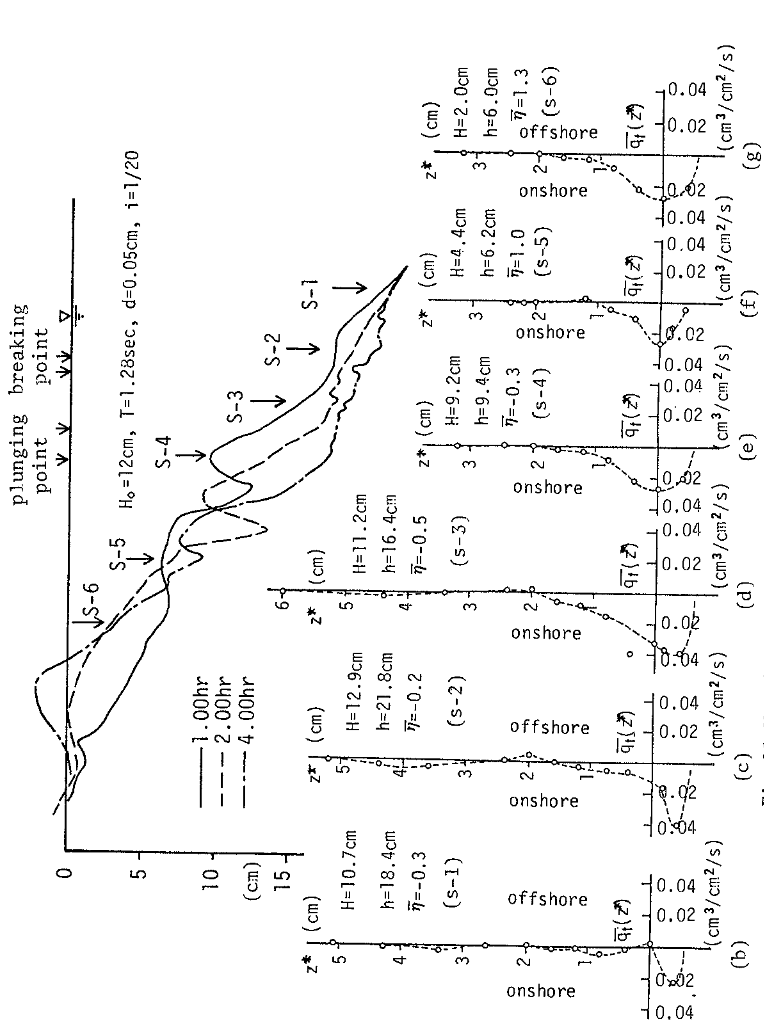


Fig.11 Vertical distribution of sediment flux (acretion type beach deformation)

water-particle velocity are known.

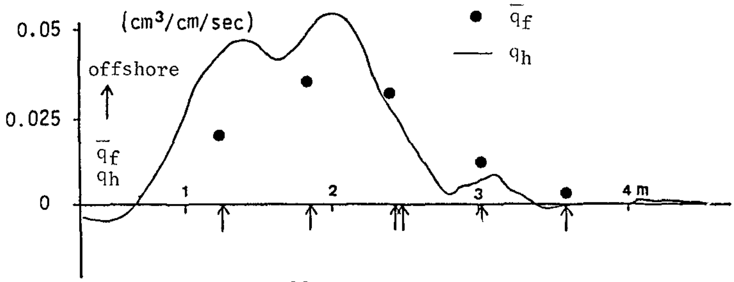


Fig.12 On-offshore sediment transport rate
(erosion type beach deformation)

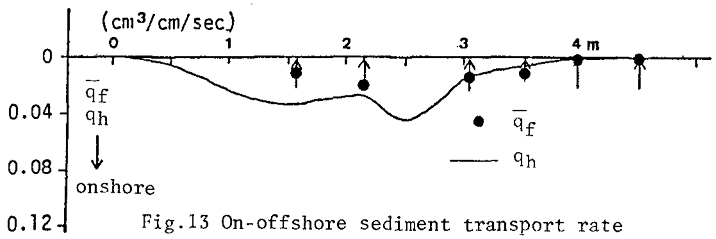


Fig.13 On-offshore sediment transport rate
(acretion type beach deformation)

4.2. Attenuation of the net rate of on-offshore sediment transport

It is well known that the net rate of on-offshore sediment transport in the two-dimensional model beach deformation process decreases exponentially with increasing wave running time(Sawaragi et al.(1980)). There seems to exist three mechanisms of this decay of net on-offshore sediment transport. One is the decay of an agitational force of the fluid acting on the bottom sediment as a result of the interaction between the beach deformation and wave deformation. In this case, time averaged sediment concentration decreases with increasing wave running time inevitably. However, time averaged concentration did not change its magnitude and vertical profile in our experiments.

Another two mechanisms are as follows:

1) net onshore sediment transport by bed load decreases owing to the change of local bottom profile and consequently, the net offshore sediment transport in suspension decreases with increasing wave running time,
2) net rate of onshore bed load transport and net rate of offshore suspended sediment transport become the same, that is, the closed loop is atteined between bed load and suspended load.

Fig.14 shows the comparison of $q_{f0.5-1.5}$ with $q_{f20-21}$ which are calculated from the measured sediment concentration during 0.5 and 1.5hrs. and during 20 and 21hrs. after waves began to incident in the process of erosion type beach deformation.

At point s-6 in the surf zone shown in Fig.(d), the decrease of net on-offshore sediment transport seems to bring about by the latter mechanism mentioned above in 2) and at another points, net on-offshore sediment transport rates appear to decay by the former machanism mentioned above in 1).

However, further detailed investigations about the time and spatial variations of sediment concentration are required to quantitatively estimate the decay of the net rate of on-offshore sediment transport.

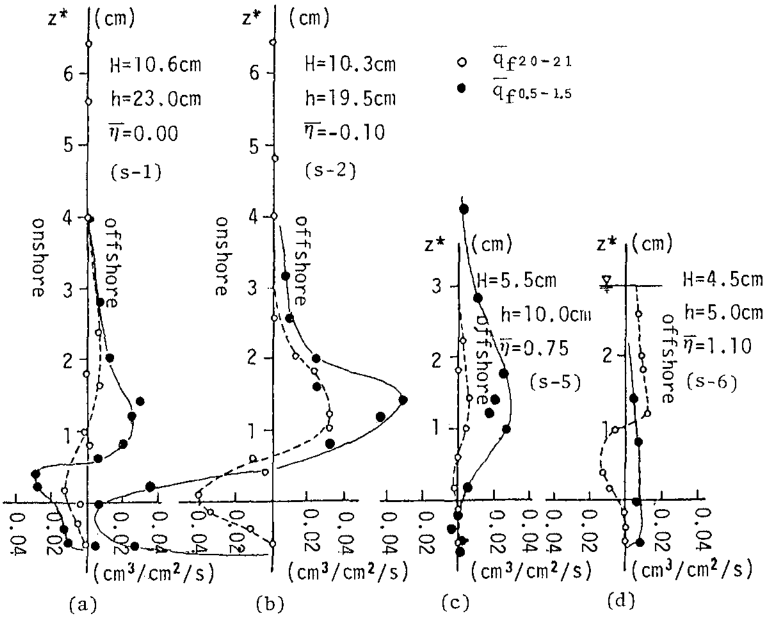


Fig.14 Decay of net on-offshore sediment transport (erosion type beach deformation)

## Concluding remarks

The net rate of on-offshore sediment transport was calculated on the basis of sediment flux by using the measured sediment concentration in two-dimensional model beach experiments and analyzed relation between water-particle velocity and the speed of sediment migration. The results coincide fairly well with the net rate of on-offshore sediment transport calculated from the change of water depth.

In that, interesting, though unverified at present, results about the velocity of the bed load layer and the thickness of the bed load layer are obtained. Some possible mechanisms which attenuate the net rate of on-offshore sediment transport are also pointed out.

The authors are proceeding further investigations about the water-particle velocity in the surfzone and the detailed mechamism of sediment movement to quantitatively predict the time and spatial variation of sediment concentration.

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