CHAPTER 54

SUSPENDED SEDIMENT AND LONGSHORE SEDIMENT TRANSPORT DATA REVIEW

BY

M. M. Das*, M. ASCE

ABSTRACT

A review of laboratory and field studies on suspended sediment under waves shows that although about five analytical or semi-empirical approaches have been attempted to predict the vertical distribution of suspended sediment, none of the approaches has had its general validity proven. This is mainly due to the lack of knowledge about the characteristics of turbulence of the wave boundary layer and to the lack of a suitable suspended sediment measuring technique for use in waves. Six different suspended sediment measuring techniques have been used in the studies reviewed. Although none of them gives completely reliable laboratory or field measurements, an optical system appears to show promise in obtaining information on the mechanics of suspension under waves.

The reanalysis of longshore sediment transport data and tests of the relationships $Q = A_1E_a$, $Q = A_2E_a^B$, and $I_\ell = A_3E_a$, where Q is volume transport rate in cubic yards per day, E_a is longshore component of wave energy flux in lbs per day per foot of beach and I_ℓ is immersed weight transport rate in lbs per day, for different subsets of data and using the method of least squares, showed that a single set of A_1, A_2 and B does not fit all subsets of data with minimum average percentage deviation of observed values from those predictable by the relationships. The subset of data consisting of all but the observations with light weight sediments can be described by the line of fit, $Q = 1.93 \times 10^{-4} E_a$, with the observed data differing from the predicted ones by 74 percent on the average.

INTRODUCTION

There is no proven prediction method of general validity for quantitative estimates of onshore-offshore and longshore sediment transport rates. The reasons are (a) inadequate knowledge of the turbulent flow field in water waves, due partly to lack of velocity measurement technique and (b) nonavailability of reliable techniques to measure sediment transport rates in the near-shore zone. It is agreed in principle that the oscillatory flow due to wave motion stirs up the sediment and makes it available for net movement by the mass transport current associated with the wave motion, or by any other net current. It has also been concluded from laboratory (Saville, 1950;Shinohara et al, 1958) and

*Research Hydraulic Engineer, U. S. Army Coastal Engineering Research Center, Washington, D. C.

field studies (Watts, 1953; Thornton, 1969; Cook and Gorsline, 1972) that sediment transport both onshore and offshore of the surf zone occurs in two modes - suspension and bed load. Equations (1) and (2) below are an expression of this. But their relative contribution to total transport still remains unspecified in both zones.

The total sediment transport rate per unit width in the zone outside the breakers can be written as,

$$q_T = q_b + q_s = \int_o^a C_0\overline{u}(y)dy + \int_a^y \overline{C}(y)\overline{u}(y)dy \quad (1)$$

where, q_b and q_s are the bed load and suspended load rates per unit width, C_0 is the average bed layer concentration, a is a measure of the thickness of bed layer, $\overline{u}(y)$ is the net current profile within the bed layer and in the interior of the fluid.

The total longshore sediment transport in the surf zone may be written as

$$Q_T = \int_o^{z_s}\int_o^a C_0(z)\overline{u}_1(y,z)dydz + \int_o^{z_s}\int_a^{h(z)} \overline{C}(y,z)\overline{u}_1(y,z)dydz \quad (2)$$

where, $\overline{u}_1$ is the net current alongshore, the z co-ordinate is the distance across the surf zone, z_s is the width of the surf zone and h(z) is the local water depth.

For better design of future studies on nearshore sediment transport, two reviews have been made, one on the existing analytical approaches to predict suspended sediment distribution, $\overline{C}(y)$, with a summary of the techniques used or under development to measure suspended sediment concentration under waves, and the other on the readily available longshore transport data (Das, 1971). The reviews are, however, not exhaustive.

SUSPENDED SEDIMENT REVIEW

The equilibrium exchange equation is given by,

$$v_s\,\overline{C}(y) = -\overline{v'c'} = -\overline{v'\ell e}\,\frac{d\overline{C}(y)}{dy} = -\varepsilon_s\,\frac{d\overline{C}(y)}{dy} \quad (3)$$

Integrating, $$\ell n\,\frac{\overline{C}(y)}{\overline{C}(a)} = -\,v_s\int_a^y \frac{dy}{\varepsilon_s} \quad (4)$$

The determination of the exchange coefficient ε_s and its relation to known or easily accessible flow parameters is the central issue of the problem of sediment suspension.

In the case of open channel flows where the entire flow is a turbulent boundary layer or shear flow, the solution of the equilibrium exchange equation (3) under the conditions of linear shear stress distribution, Kármán's log-velocity distribution, and the Reynolds analogy between the momentum and mass diffusion coefficients defines the vertical distribution of suspended sediment concentration in terms of a reference concentration (Rouse, 1937) as,

$$\frac{\bar{C}(y)}{\bar{C}(a)} = \left(\frac{h-y}{y} \cdot \frac{a}{h-a}\right)^z \tag{5}$$

where, $z = (v_s/\kappa U_*)$.

It is widely used in unidirectional flows. Bijker (1971) used it for computation of suspended sediment transport in the combination of waves and current and reported good agreement between measured and computed values of longshore transport.

In the case of waves, the boundary layer, usually very thin compared to the entire depth of flow, is the only source of turbulence to cause suspension of bed material, except near the breakers. Therefore, knowledge of the boundary layer turbulence is necessary to predict the distribution of suspended sediment concentration.

ANALYTICAL APPROACHES

If the exchange coefficient ε_s, is independent of the space variable y, then one obtains the exponential distribution of mean concentration from equation (4).

$$\frac{\bar{C}(y)}{\bar{C}(a)} = \exp\left[-\frac{v_s}{\varepsilon_s}(y-a)\right] \tag{6}$$

The experimental results of Shinohara et al (1958) from a sloping beach with 0.2 mm sand and 0.3 mm pulverized coal showed the mean concentration to be exponentially distributed with depth. Figure (1) is a typical result from Shinohara et al with coal as sediment. Unlike the profiles with sand the concentration profile with coal shows a break point and this break point was considered as the lower limit of suspension. Using equation (6) and the known value of the settling velocity v_s, the exchange coefficient ε_s was calculated at various sections along the beach. The coefficient was found to increase slowly with decrease of depth, increasing faster before breaking and attaining maximum value near the breaker point and then decreasing shorewards, the decrease being faster in case of pulverized coal.

Hom-ma and Horikawa (1962) obtained a solution of the equilibrium exchange equation with the following assumptions. Prandtl's type mixing length hypothesis was used to characterize the eddy diffusion coefficient,

$$\varepsilon_y = \beta b^2 \left| \frac{du}{dy} \right| \tag{7}$$

where β is a constant, b is the vertical dimension of the water particle orbit, and u is the horizontal velocity of the water particle due to wave motion. Airy's wave theory was used to obtain b and u. The temporal variation of mean concentration during a wave period was expressed in the form,

$$C = \overline{C}(y)\ [1 + \xi \sin 2\ (kx - \frac{2\pi t}{T})] \tag{8}$$

where C is the instantaneous concentration, k is the wave number, and ξ is a constant. Under the above assumptions the solution of the steady state diffusion equation was obtained as,

$$\frac{\overline{C}(y)}{\overline{C}(a)} = \exp\ [-\alpha \frac{v_s}{c} (\frac{H}{L})^3 (\frac{h}{L}) \operatorname{Sinh}^3 kh\ (F(n,kh)] \tag{9}$$

where, $n = \frac{y}{h},\ n_a = \frac{h-a}{h},\ \alpha = \frac{3}{\beta},\ c = \frac{L}{T}$.

$$F(n,kh) = \frac{1}{2kh} \left[\frac{\operatorname{Cosh} kn_a h}{\operatorname{Sinh}^2 kn_a h} - \frac{\operatorname{Cosh} knh}{\operatorname{Sinh}^2 knh} \right] + \log \left| \frac{\tanh \frac{kn_a h}{2}}{\tanh \frac{knh}{2}} \right|$$

in which $\overline{C}$ (a) is the mean concentration at a reference depth above the bed, h is the undisturbed water depth, L is the wave length, H is the wave height, v_s is the settling velocity, and T is the wave period. The agreement between the theory and the experimental results was reported to be satisfactory.

Hom-ma, Horikawa, and Kajima (1965) modified the distribution function (9), by using Kármán's mixing length hypothesis,

$$\varepsilon_y = \kappa\ \ell^2 \left| \frac{du}{dy} \right| \tag{10}$$

and considering empirically the effects of ripple geometry on suspension. Velocity u, and the mixing length ℓ were determined from potential wave theory, and ε_y was given as,

$$\varepsilon_y = \frac{1}{K} \frac{Hc}{\operatorname{Sinh} kh} \frac{\operatorname{Sinh}^3 k(y+h)}{\operatorname{Cosh}^2 k(y+h)} \tag{11}$$

The concentration distribution was given by

$$\frac{\bar{C}(y)}{\bar{C}(a)} = \exp\left\{-K\frac{v_s}{cH}\,\frac{\text{Sinh}kh}{2k}\,[F(n_a,\ kh) - F\ (n,\ kh)]\right\} \tag{12}$$

where,

$$F(n,\ kh) = \frac{\text{Cosh}\ nkh}{\text{Sinh}^2 nkh} - \log\left|\tanh\frac{nkh}{2}\right|$$

and,

$$n = \frac{y+h}{h},\ n_a = \frac{h-a}{h},\ c = \frac{L}{T}$$

The value of n_a was chosen arbitrarily as 0.05 and 0.1 in the analysis of laboratory and field data respectively.

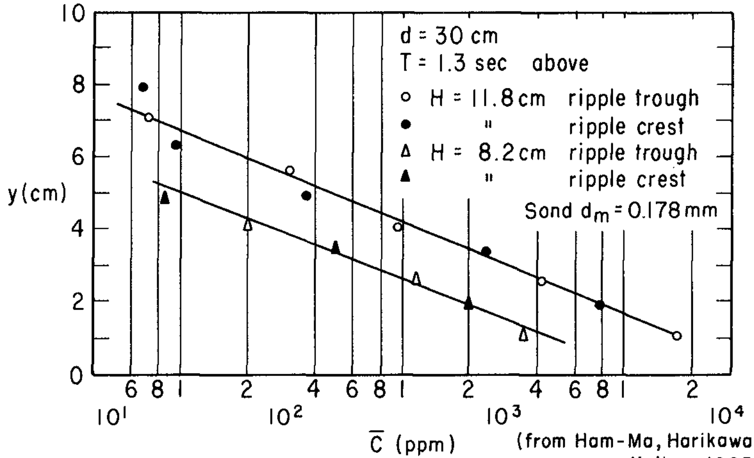
The values of K were determined using the equation (12) from the measurements of mean concentration in the field and laboratory and were found to be a function of the relative depth n and a function of $\frac{H}{L}\cdot\frac{h}{\eta}$ or $\frac{H}{L}\cdot\frac{h}{\lambda}$ where η and λ are the height and length of the ripples respectively. The equation for K was obtained graphically as,

$$K = 0.161\ \left(\frac{y+h}{h}\right)^{0.833}\left(\frac{H}{L}\cdot\frac{H}{\lambda}\right)^{0.142}\left(\frac{H}{\lambda\sinh kh}\right)^{0.270} \tag{13}$$

from best fits of available data. While the effect of ripple geometry on sediment suspension is considered, the inconsistency of using potential velocity to derive turbulent diffusion coefficient existed and also the arbitrariness in the choice of the reference depth and concentration persisted. Fig. 1 shows a typical experimental result of Hom-ma et al (1965) using a horizontal bed of 0.178mm sand.The distributions of mean concentration both above a ripple crest and trough appear to be exponential as suggested by equation (12).

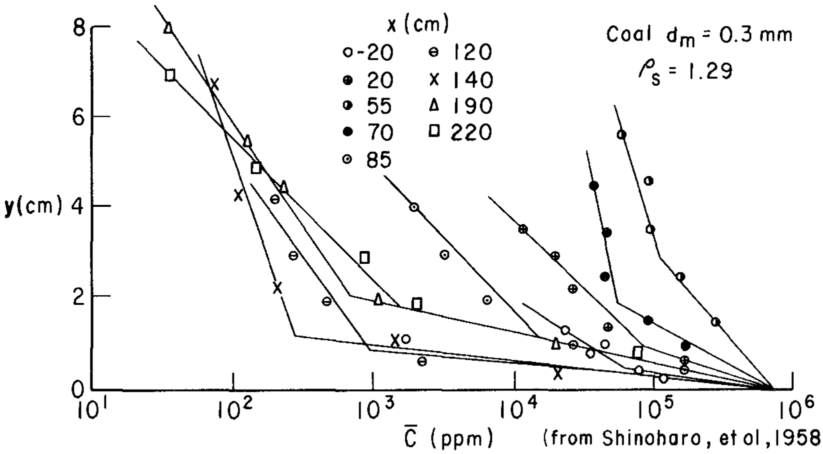
Noda (1967, 1971) derived the one-dimensional mass balance equation from the complete two-dimensional unsteady mass conservation equation under some simplifying assumptions. His measurements of suspended sediment concentration under standing waves using poly vinyl chloride grains of 0.13 mm diameter and of 1.13 specific gravity yielded profiles similar to those of Shinohara et al (1958) with pulverized coal.

From a comparison of the distributions of ε_s derived from his experimental results, from those of Hom-ma, Horikawa and Kajima (1965) and from the available field measurements and using the eddy diffusivity models of Hom-ma and Horikawa (1962), Hom-ma, Horikawa and Kajima (1965), Kishi (1964) and Kajiura (1964) he concluded that the distribution of ε_s was strongly dependent on the flow conditions near the bed and the bed roughness.



(from Ham-Ma, Horikawa, Kajima, 1965)

DISTRIBUTION OF $\overline{C}$



(from Shinoharo, et al, 1958)

FIGURE 1. DISTRIBUTION OF $\overline{C}$

Noda (1971) assumed a constant ε_s and expressed the vertical distribution of concentration as,

$$\frac{\bar{C}(y)}{\bar{C}(a)} = \exp\left[-\left(\frac{v_s h}{\nu}\right)\left(\frac{\nu}{\varepsilon_s}\right)\left(\frac{y-a}{h}\right)\right] \quad (14)$$

He tried to investigate the relationship between the agitation parameter $\frac{\varepsilon_s}{\nu}$ and Reynolds number $\frac{U_o\delta}{\nu}$ ($\delta = \sqrt{\nu T/2\pi}$, U_o = amplitude of bottom velocity) using the mean concentration data above the break point in the profile where ε_y is constant. He also attempted to relate nondimensionalized height of the break point in the mean concentration profile, $\frac{a}{\delta}$ to $\frac{U_o\delta}{\nu}$. Since the range of Reynolds number in the data was narrow (60-200) he could not arrive at definite conclusions. But he felt that the height of break point was closely connected with the size of sand ripples and the diameter of the eddies they generate. He also felt that detailed study of the velocity field near the ripples was necessary for further clarification of the mean concentration profiles.

Hattori (1969) presented an analytical approach for two-dimensional distribution of suspended sediment concentration under standing waves. In this approach he introduced a delay distance caused by the relative motion between the sediment and fluid particles. He assumed the coefficient of diffusion and delay distance to be independent of space variables. He also assumed the instantaneous concentration to be made up of a mean and a fluctuation from the mean given as:

$$C(x,y,t) = \bar{C}(x,y) + C_j'(x,y)\sin 2j\omega t \quad (15)$$

where $\omega = \frac{2\pi}{T}$ and C_j' is the concentration fluctuation.

Under the above assumptions the distribution of mean concentration of suspended sediment under a standing wave was obtained as,

$$\bar{C}(x,y) = \bar{C}(o, a)\exp\left[\alpha(1-\text{Cos}kx) - \frac{\beta}{h}(y-a)\right] \quad (16)$$

where $\alpha = 2HL|\delta_x|/\pi\varepsilon_{sx}Th$

$\beta = v_s h/\varepsilon_{sy}$

δ_x is the delay distance and ε_{sx} and ε_{sy} are diffusion coefficients in the x and y directions respectively. He found close agreement between his theoretical and experimental results (1969, 1971) on horizontal and vertical distribution of mean concentration under standing waves. Fig. 2 shows typical experimental results of Hattori (1969) and of Noda (1967). The agreement between theory and experiment is, however, dependent on the suitable choice of the parameters α and β, which in turn depend on the unknown quantities δ_x, ε_{sx} and ε_{sy}. Hattori (1971) obtained relationship between the delay distance δ_x and the characteristics of standing waves, on the assumption that the diffusion coefficient in the horizontal direction is almost equal to that in the vertical direction. The relationship obtained is,

$$\frac{|\delta_x|}{\xi} = 1.35\ (v_s/u)^{3/2} . \tag{17}$$

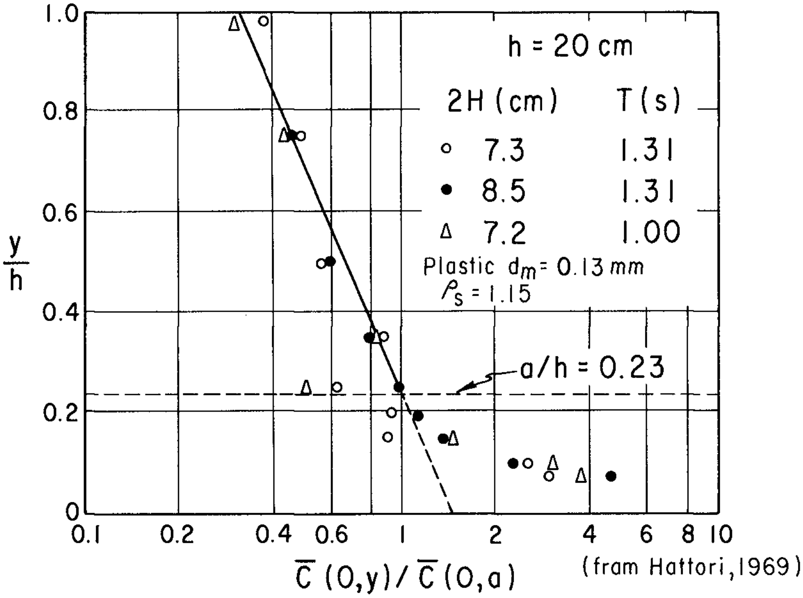
where $\xi = \frac{H}{h/L}$, a quantity proportional to the amplitude of the mean horizontal displacement, and u is the amplitude of the mean horizontal velocity of fluid particles under standing waves. Further his experimental results showed that the delay distance in the horizontal direction has a tendency to decrease with the increase in the mean horizontal velocity of fluid particles.

If the exchange coefficient is linearly dependent on the space variable y, the resulting concentration distribution would be linear on a log-log plot. The results of Kishi (1964), Bhattacharya (1971) and Das (1971) show such a tendency (Fig. 3). The results of Das (1971) were obtained in a swing flume where the oscillary boundary layer flow is reproduced on a prototype scale.

In data shown in Fig. 4, Horikawa and Watanabe (1968) attempted to demonstrate the agreement between the calculated eddy diffusivity using the constant eddy diffusivity model proposed by Kajiura (1964) for the inner layer and the estimated ε_y from measured distribution of mean concentration. Although acceptable agreement is apparent from the figure, the applicability of the Kajiura's eddy diffusivity model deserves further consideration. In bottom Fig. 4 Horikawa and Watanabe (1970) compared the eddy diffusivity ε_y obtained from point measurements of turbulent velocity fluctuations with the exchange coefficient determined from measured distribution of mean concentration. The authors have felt it necessary to improve their instrumentation techniques to attain greater accuracy in such measurements, needed for explication of the suspension mechanism under waves.

Using Bagnold's energy principle approach, Thornton (1969) proposed the following relationships for the mean suspended sediment transport rate per unit width of the profile outside the surf zone,

$$\bar{q}_s = \frac{S}{g(1-\frac{\rho}{\rho_s})}\ \frac{V}{v_s}\ \left|\overline{u_{wh}\ \tau_h}\right| \tag{18}$$



EXPERIMENTAL VALUES FROM NODA, 1967

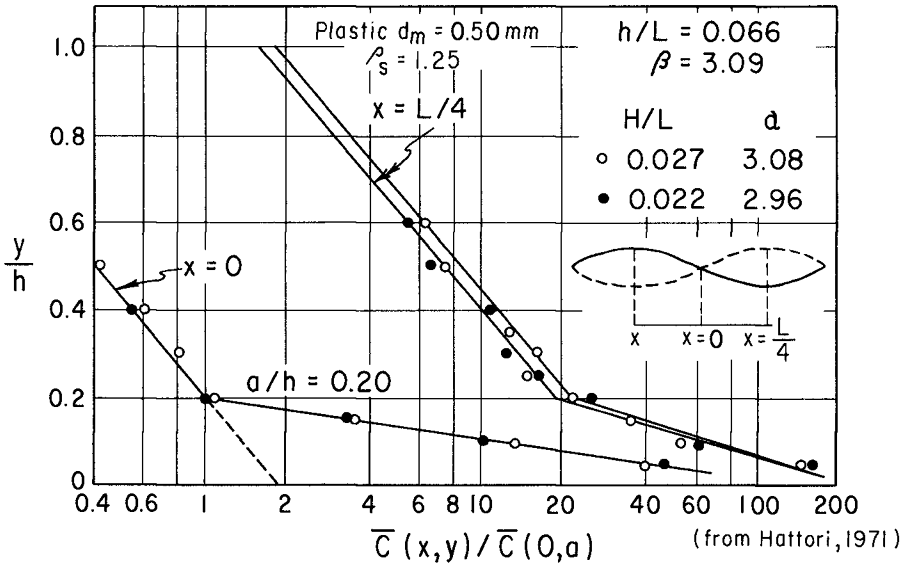
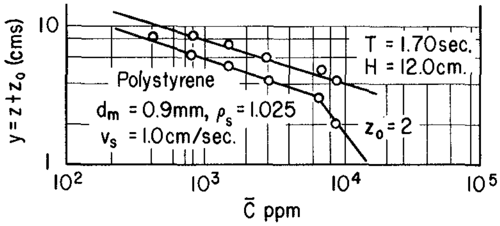
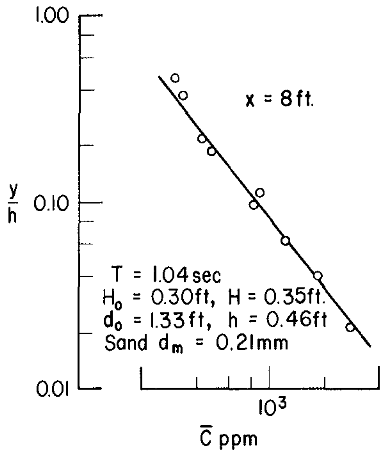


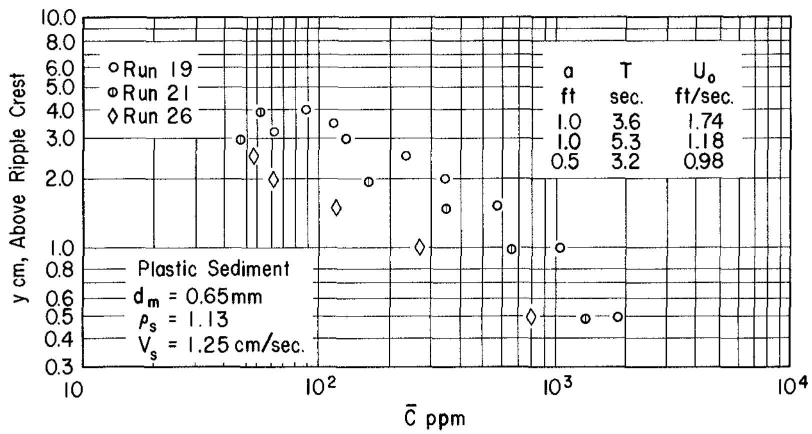
FIGURE 2. VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT CONCENTRATION (STANDING WAVES)



(Fram Kishi, 1964)

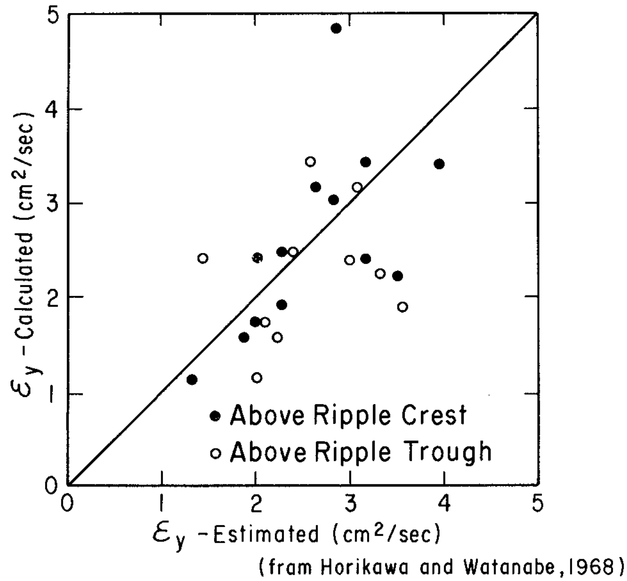


(From Bhattacharya & Kennedy, 1971)



(From Das, 1971)

FIGURE 3. DISTRIBUTION OF $\bar{C}$



COMPARISON BETWEEN ESTIMATED AND CALCULATED $\mathcal{E}_y$

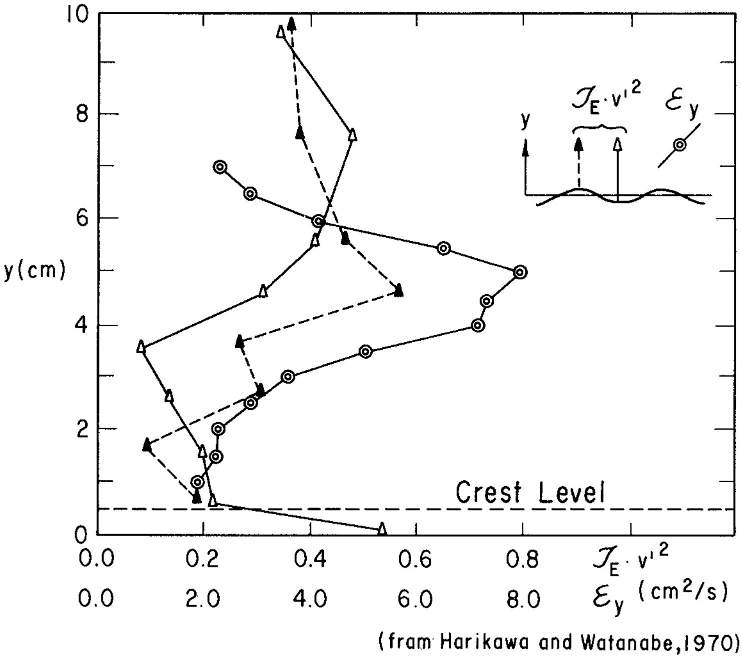


FIGURE 4. COMPARISON BETWEEN $\mathcal{T}_E \cdot v'^2$ AND $\mathcal{E}_y$

and inside the surf zone,

$$\overline{q_s} = \frac{-S_s}{g(1 - \frac{\rho}{\rho_s})} \frac{V}{v_s} \frac{\partial ECg}{\partial x} \tag{19}$$

where S and S_s are proportionality factors associated with suspended sediment transport, V is mean velocity component parallel to the beach, u_{wh} is water particle velocity due to wave motion at the bed, τ_h is shear stress at the bed, E is wave energy density, Cg is group velocity, and ρ and ρ_s are densities of fluid and sediment respectively. No measurements of suspended sediment transport rates are reported in the study for verification of the proposed relationships.

Bhattacharya (1970) and Kennedy and Locher (1971), time-integrating the complete two-dimensional mass conservation equation under the assumption of $\frac{\partial}{\partial x} << \frac{\partial}{\partial y}$ and using the concept of a delay time between motions of sediment and fluid particles similar to the delay distance concept of Hattori (1969), obtained the one-dimensional mass conservation equation given as,

$$\overline{C_p \, [v_p - \tau \frac{\partial v_p}{\partial t}]} - v_s \, \overline{C} = \varepsilon_y \frac{d\overline{C}}{dy} \tag{20}$$

where, C_p is the periodic component of concentration and v_p is the vertical component of fluid velocity due to orbital motion and τ is the delay time. However, motion picture photography of sediment suspension process led Kennedy and Locher (1971) to postulate that the periodic part of velocity near the bed is composed of wave orbital motion, velocity due to the eddies and the velocity perturbation due to the waviness of the bed. Therefore C_p also includes all the three above effects and the convective term $\overline{C_p[v_p - \tau \frac{\partial v_p}{\partial t}]}$ reflects suspension due to all the three effects. But considering ε_y and τ as constant and only the effect due to vertical orbital motion v_p Bhattacharya (1970) and Kennedy and Locher (1971) obtained the solution to (20) as,

$$\frac{d\overline{C}}{dy} \left[\frac{\tau k_1 \eta^2 \sigma^2}{2h^2} y^2 + \varepsilon_y \right] = - v_s \, \overline{C} \tag{21}$$

and upon integration,

$$\ln \frac{\overline{C}o}{\overline{C}(y)} = \frac{hv_s}{\eta\sigma\sqrt{\frac{\tau k_1 \varepsilon_y}{2}}} \tan^{-1} \left\{ \frac{\eta\sigma}{h} \sqrt{\frac{\tau k_1}{2\varepsilon_y}} \frac{y - y_o}{1 + \frac{\eta\sigma}{h} \sqrt{\frac{\tau k_1}{2\varepsilon_y}}\, yy_o} \right\} \quad (22)$$

where h is the undisturbed water-depth, η is wave amplitude and $\sigma = \frac{2\pi}{T}$.

Arguing that turbulent diffusion under wave motion is limited to regions near the boundary and wave induced convection dominates in the interior of the fluid, ε_y can be approximated to zero. With this argument Kennedy and Locher (1971) obtained the following distribution function from (20).

$$\ln \frac{\overline{C}(y)}{\overline{C}o} = \frac{2v_s h^2}{\tau k_1 \eta^2 \sigma^2} \left[\frac{1}{y} - \frac{1}{y_o}\right] \quad (23)$$

Arguing the other way that close to the bed turbulence is predominant and wave induced convection is small and therefore considering $k_1 = 0$ the classical Schmidt equation was obtained,

$$v_s \overline{C} + \varepsilon_y \frac{d\overline{C}}{dy} = 0, \quad (24)$$

considering the functional dependence of ε_y as,

$$\left(\frac{\varepsilon_y}{\varepsilon_o}\right) = \left(\frac{y}{y_o}\right)^{\alpha} \quad (25)$$

where $\varepsilon_o = \varepsilon_y\,(y_o)$. Kennedy and Locher (1971) obtained the following distribution functions after integration of (24),

$$\alpha = 1 \qquad \frac{\overline{C}(y)}{\overline{C}_o} = \left(\frac{y}{y_o}\right)^{\frac{-v_s y_o}{\varepsilon_o}} \quad (26)$$

$$\alpha \neq 1 \qquad \ln \frac{\overline{C}(y)}{\overline{C}_o} = \frac{v_s y_o}{(1 - \alpha)\,\varepsilon_o} \left[1 - \left(\frac{y_o}{y}\right)^{\alpha - 1}\right] \quad (27)$$

$$\alpha = 0 \qquad \frac{\overline{C}(y)}{\overline{C}_o} = \exp\left[-\frac{v_s}{\varepsilon_o}(y - y_o)\right] \quad (28$$

Bhattacharya's (1970) experimental results from a laboratory study under equilibrium sloping beach conditions using .21 mm quartz sand did not support the distribution functions (22), (23) and (28). His results of mean concentration $\overline{C}$ varied linearly with depth on a logarithmic graph (middle Fig. 3) suggesting a power type distribution given as,

$$\frac{\overline{C}(y)}{\overline{C}_o} = \left(\frac{y}{h}\right)^{-z} \tag{29}$$

which corresponds to the distribution given by (26).

Bhattacharya (1970) then used a simple dimensional analysis to determine the exponent z, and found to be equal to $\frac{v_s T}{\varepsilon_o h}$ where

$$\varepsilon_o = \frac{\varepsilon_y T}{hy} = f\left(\frac{\eta}{h}, \frac{\eta}{gT^2}\right) \tag{30}$$

Using his experimental results he obtained the variation of ε_o against h/η with η/gT^2 as a parameter.

Kennedy and Locher (1971) from further tests using horizontal bed with fixed ripples and using small quantity of 0.14 mm diameter sand, tried to verify the validity of the mean concentration distribution functions given by (22), (23), (26) and (28). The fixed bed ripples were used with the purpose of removing the arbitrariness in defining the depth of concentration measurements due to ripple migration and change of ripple height. The electro-optical meter utilized in Bhattacharya's study (1970) was further developed for higher sensitivity and better performance and smaller sediment size was used to increase measurement accuracy at lower concentrations at higher distances from the bed. The verification yielded positive results for all the four functions in their expected regions of validity. Fig. 5 displays a typical example of data verifying the distribution given by equation (26).

SUMMARY

Analytical approaches:

The four or five analytical approaches which exist to predict the suspended sediment distributions simply illustrate the complex nature of the problem of sediment suspension under waves. A satisfactory solution to the problem still does not exist. It must be recognized that turbulence is the major cause of suspension of sediment in a turbulent flow. The only source of turbulence under waves is the boundary layer, except near breakers. In the equilibrium exchange equation the effect of turbulence is considered through the exchange coefficient. Future research must, therefore, concentrate on the detailed study of the boundary layer turbulence and hence the exchange coefficient. Precise measurements of suspended sediment concentration under suitable flow conditions and with properly developed instrumentation will supplement the effort on the determination of the exchange coefficient from measurements of boundary layer turbulence and its relation to flow parameters and bed roughness. This will provide a relative distribution of concentration in terms of a reference concentration C_o, which may be determined

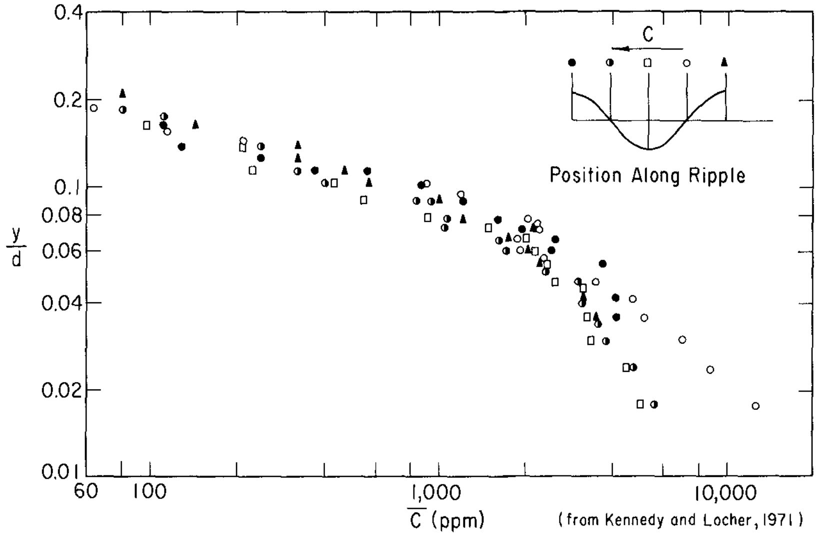


FIGURE 5. VARIATION OF $\overline{C}$ WITH y/d

from the basic approach presented by Einstein (1971). However, in order to be able to compute the net transport rate in any direction the next problem would be to obtain the distribution of net current in that direction in the suspension layer as indicated by equation (1). This problem will continue to be a field of active research for several years to come.

Suspended sediment measuring techniques:

Three types of time-integrated samplers, namely pump samplers (Watts, 1953; Fairchild, 1956; 1959; Noda, 1967, 1971), syphon samplers (Shinohara et al, 1958; Hom-ma and Horikawa, 1962) and bamboo samplers (Fukushima and Mizoguchi, 1958; Fukushima and Kashiwamura, 1959; Noda, 1967) and three types of in situ measuring techniques, namely photography (Bijker, 1971), various configurations of electro-optical meters (Hom-ma, Horikawa and Kajima, 1965; Horikawa and Wantanabe, 1970; Noda, 1971; Bhattacharya, 1970; Bhattacharya and Kennedy, 1971; Kennedy and Locher, 1971; Das, 1971) and electronic particle counter (Hattori, 1969, 1971) have been used in the studies reviewed. In laboratory applications negligible disturbance to flow and precision in measurements are the most important requirements. Quantities to be measured are the long time mean and unsteady mean concentrations at a point. Although a random concentration fluctuation does exist conceptually, its measurement using sediment particles is apparently difficult to interpret. It appears that the electro-optical meters offer the best possibility in most laboratory applications. With suitable design this can be used in the field. A particle counter appears to be good at low concentrations, where the probability of two or more particles occupying the probe volume simultaneously is very small. However, the particle velocity must be determined in order to compute concentration from particle counts. Pump samplers with their sampling efficiency properly evaluated are simple and easily operable tools for field applications.

LONGSHORE SEDIMENT TRANSPORT DATA REVIEW

The longshore transport data compiled by Das (1971) form the basis of this review and analysis. The data are taken from six laboratory studies with 177 observations and from four field studies with 25 observations. An observation has been defined here as a data point, for which the transport rate and the associated wave and sediment characteristics are known. The purposes of the review were to see if the empirical relationships between longshore transport rate and the alongshore component of wave energy flux could fit the available data with reasonable scatter and specifically to up-date the visual line of fit in CERC TR-4.

The relationships tested were $Q = A_1 E_a$, $Q = A_2 E_a^B$ and $I_\ell = A_3 E_a$ where, Q is volume transport rate in cubic yards per day, E_a is alongshore component of wave energy flux in lbs per day per foot of beach and I_ℓ is immersed weight transport rate in lbs per day. The volume transport rate Q is related to the immersed weight transport rate I_ℓ (Bagnold, 1963) by,

$$I_\ell = (\rho_s - \rho) g a' Q \tag{31}$$

where, a' is a correction factor for pore space and it has been assumed as 0.6 in the analysis. The alongshore wave energy flux E_a has been computed in the 177 laboratory observations by using the relationship suggested in CERC TR-4.

$$E_a = \frac{E_o}{2} N K_R^2 \sin \alpha_b \cos \alpha_b \tag{32}$$

where $E_o = \frac{\gamma H_o^2 L_o}{8}$, γ is unit weight of sea water H_o and L_o are deep water wave height and wave length, N is number of waves per day, K_R is refraction coefficient and α_b is the breaker angle.

In case of the field studies of Watts (1953), Caldwell (1956) and Komar (1969), the energy flux computed by the investigators have been used, except that the energy flux values of Watts and Caldwell were reduced by a factor 2 to correspond to energy based on root-mean-square wave height, rather than the significant wave height used by them (Inman and Frautschy, 1966). This is consistent with the theoretical prediction of Longuet-Higgins (1952) for narrow band wave spectrum with waves of random phases.

Fig. 6 is the plot of Q vrs E_a for the data reviewed. The data of Johnson (1952) and of Thornton (1969) are also plotted. But these two sets of data are not included in the least square procedure to examine the empirical relationships. The reasons are that Johnson's data do not include the observation of wave angles and Thornton's data do not provide transport measurement across the whole width of the surf zone and, moreover, he apparently measured only the bed load transport. The figure shows only two lines of best fit using $Q = A_1 E_a$ for all data and for all but light weight material data and the line proposed in CERC TR-4. Figure 7 shows only the scatter-areas of plots of I_ℓ against E_a. The reduction of scatter in laboratory data due to inclusion of density of material in I_ℓ can be noticed. In this figure are shown the line of best fit now obtained for all available data, the line proposed by Komar (1969) for field data and the line proposed by Inman and Frautschy (1966) on the basis of data available at that time and using significant wave energy flux for the data of Watts and Caldwell.

SUMMARY

As a rule-of-thumb the volume rate relationship $Q = 1.93 \times 10^{-4} E_a$ where Q is in cubic yards per day and E_a is in ft-lbs per day per foot of beach, or the immersed weight rate relationship $I_\ell = .35\ E_a$ may be used as a guide. It is suggested and also indicated by equation (2) that the near-future studies, both in the laboratory and in the field should include, (1) simultaneous measurements of bed load and suspended load; (2) simultaneous measurement of velocity field in and shoreward of the breaker zone and the imposed wave conditions, and that systematic laboratory studies be made to evaluate scale model relationships by simulating known prototype conditions for better interpretation and the extrapolation of laboratory data to field conditions.

ACKNOWLEDGEMENT: Data presented in this paper, unless otherwise noted, were obtained from research conducted by the United States Army Coastal Engineering Research Center under the Civil Works research and development program of the United States Army Corps of Engineers. Permission of the Chief of Engineers to publish this information is appreciated. The findings of this paper are not to be construed as official Department of the Army position unless so designated by other authorized documents.

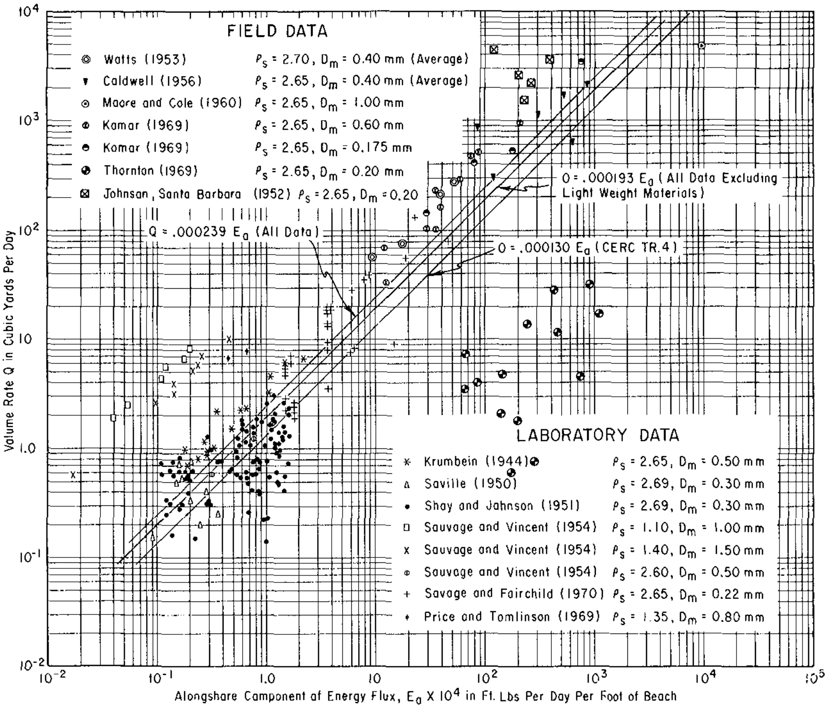


FIGURE 6. RELATION BETWEEN Q AND E_a

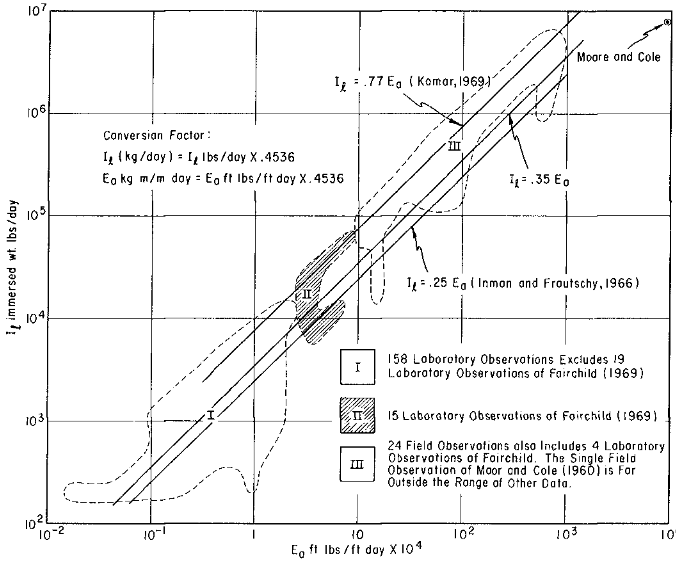


FIGURE 7. RELATION BETWEEN IMMERSED WEIGHT LITTORAL TRANSPORT RATE I_ℓ AND LONGSHORE COMPONENT OF WAVE ENERGY FLUX PER UNIT LENGTH OF BEACH E_a

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