# CHAPTER 120

### TRANSIENT RIPPLE FORMATION AND SEDIMENT TRANSPORT

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### ABSTRACT

A knowledge of sediment transport rates due to wave action is essential for an understanding of various coastal engineering problems. Many problems have to be resolved before successful measurement can be made for sediment transport rates due to waves.

Since gradients of sediment transport cause changes of beach morphology, the sediment transport rate outside breaker can be determined from measured beach changes. Measurements of ripple growth and migration yield their mathematical descriptions in the same manner as those of surface waves. Expressions of sediment transport rates are then derived.

It is found from the study that the sediment transport rates are strongly controlled by the rates of growth and migration of ripples.

# INTRODUCTION

Passage of water waves over an erodible bed of sands produces an oscillatory sediment transport. Due to wave action, the initially straight bed is deformed into wavy undulations known as ripples. These ripples will grow in height and length until they attain in equilibrium geometry for a set of wave-beach characteristics. The phenomenon of ripple formation due to wave action is of considerable interest due to a resulting contribution to sediment transport. In addition, the ripples on the bed significantly affect wave attenuation, wave induced current and beach profile. Not much data on transient ripple formation and migration are presently available despite the fact that they are needed to determine the sediment transport rate due to ripple migration.

The objectives of this study are to quantify the growth and migration of ripples due to wave action normal to beaches outside breaker lines from experimental results in a wave flume, and to determine the resulting rate of sediment transport. Since the offshore sediment transport does not yield a well defined ripple migration, only the onshore ripple migration and sediment transport are presented. This report is prepared from two master theses of Gunaratna (1984) and Munasinghe (1985).

## SURVEY OF EARLIER WORK

Reviews will first be made on geometries of stable, not transient, ripples generated by oscillatory flows and followed by rates of sediment transport generated by oscillatory flows.

<sup>1</sup> Professor and <sup>2</sup> Graduate Students, Div. of Water Resources Engrg., Asian Inst. of Tech., P.O. Box 2754, Bangkok 10501, Thailand. Ripple Geometry.- Ripple geometries generated by oscillating bed were first tested by Bagnold (1946) and Manohar (1955). Prototype ripples were measured by Imman (1957) and Dingler (1974). Extensive laboratory tests on ripple geometries were made by Mogridge and Kamphuis (1972). Analysis was made on ripple geometries by Vongvisessomjai (1984) using published and supplementary data tested by the author. These studies reveal that, when the bed shear stress of an oscillatory fluid exceeds the critical value required for initial motion on a flat sediment bed, rolling grain ripples will slowly form; as the shear stress increases, the height and length of ripples will also increase accordingly. The growing ripples continue to enlarge as the bed shear stresses reach higher values until optimum condition is reached. Beyond this stage, the ripple height will decay, while its length remains practically constant or decays slowly.

Empirical Rate of Sediment Transport.- Almost all empirical formulae of sediment transport rates were developed from oscillating bed data, only that proposed by Vongvisessomjai (1986) was developed from wave flume data.

Manohar (1955) employed an oscillating bed of sediment to study regimes of sediment transport, ripple geometries and rates of sediment transport. He found the governing parameter of all the phenomena to be

in which  $U_{lm}$  = maximum orbital velocity of fluid just outside boundary layer; s = relative density of sediment; g = gravitational acceleration; V = kinematic viscosity of fluid; and D = mean or median diameter of sediment.

In order to obtain rates of sediment transport, he generated asymmetrical motion by changing the angular frequencies of a flywheel driving the oscillating bed when it was at its extreme positions, while he held the amplitudes of the excursions constant. These asymmetrical motions yield a net sediment transport, the sediment being collected in a tray set into the sediment bed.

Kalkanis (1964) and Abou-Seida (1965) developed a relationship between the flow intensity  $\psi_2$  and the bed load intensity  $\phi_*$ , using the principle of Einstein's theory (1950) for sediment transport in open channels and introducing the effect of wave motion on the bed sediment. Their experimental data were obtained on oscillating beds. They found that Einstein's bed load equation for sediment transport in open channels was the same as that describing sediment transport induced by oscillating beds. This was so when the mean fluid velocity in open channels, used in defining  $\psi_2$ , was replaced by the amplitude of the oscillating bed velocity  $U_a$ , calculated at a distance 0.35D from the mean level of the bed.

and

unit width; and  $\gamma_s$  = the sepcific weight of the bed sediment. When  $U_a$  is correlated with  $U_{lm}$ , their relationship is  $U_a \div 0.625 U_{lm}$ .

Madsen and Grant (1976) re-analyzed data of Manohar (1955) Kalkanis (1964) and Abou-Seida (1965) and expressed the volumetric rate of gross sediment transport, mornalized by the settling velocity and the diameter of the sediment, as function of the Shields parameter. They stated that in Kalkanis (1964) and in Abou-Seida (1965) ripples might have been present, and for Manohar (1955), ripples were present. However, the Shields parameter was computed using Jonsson's friction factor (1966) and based on grain diameter.

Sleath (1978) used a motion picture camera to determine the instantaneous and mean sediment transport rates averaged over a half cycle induced by an oscillating bed on flat sediment beds. From his data and those of Kalkanis (1964) and Abou-Seida (1965) he obtained an expression for the mean volumetric rate of the gross sediment transport per unit width  $q'_v$  from his data and those of Kalkanis (1964) and Abou-Seida (1965):

 $\frac{q_v'}{wD^2} = 47(\psi_* - \psi_{*c})^{3/2} \qquad (4)$ in which  $\psi_{*c}$  = the critical value of Shields parameter  $\psi_*$  for initial

motion;  $\omega = 2\pi/T =$  angular velocity; and T = period of oscillation. His expression of the friction factor was the same as that obtained by Jonsson (1966) and his equivalent sand roughness was taken to be the sediment grain size. Note that Grant and Madsen (1982) found a remarkable difference between friction factors of immobile and mobile beds with sediment suspension.

Sleath's instantaneous sediment transport rate  $\boldsymbol{q}_{\boldsymbol{V}}\left(t\right)$  for sand and gravel was

$$\mathbf{q}_{\mathbf{v}}^{\prime}(\mathsf{t}) = \frac{8}{3} \mathbf{q}_{\mathbf{v}}^{\prime} \cos^{3}(\omega \mathsf{t} + \alpha) \left| \cos(\omega \mathsf{t} + \alpha) \right| \qquad (5)$$

in which t = the time;  $q_s^* = (1-\beta)\gamma_s q_V$ ;  $\beta$  = porosity of bed sediment; and  $\alpha$  = the phase lag of the local velocity behind the water surface

$$\alpha = 0.15 + 0.000018 \frac{q'_v}{\omega D^2} (\frac{a_{1m}}{D}) \frac{U_{1m}}{(\omega v)^{1/2}}$$
 (6)

in which  $a_{lm} = U_{lm}/\omega$  = nearbed amplitude of water particle excursion.

Kobayash<sup>i</sup><sup>(1)</sup>(1982)<sup>(i)</sup> derived a criterion for the initiation of sediment movement on a gentle slope by balancing the forces acting on a sediment particle lying on the slope. A relationship for the instantaneous rate of the bed load transport on a gentle slope, which was quite similar in form to that of Madsen and Grant (1976), was then derived from a simple and quasi-steady analysis of the motion of sediment particles. His theory was in reasonable agreement with experiments, conducted on horizontal beds by Kalkanis (1964), Abou-Seida (1965) and Sleath (1978).

Vongvisessomjai (1986) found from analyses of sediment transport data from oscillating beds and wave flumes that they were different. The sediment transport rate developed from wave flume data was as follows: For bed load transport (Fd<sub>\*</sub> < 4)

For total load transport (Fd, > 4)

in which the densimetric sediment Froude number  $Fd_* = U_{1m}^2/[(s-1)gD]$ .

#### METHODOLOGY

Basing on a theoretical model to explain the formation of wavegenerated sediment ripples presented by Kennedy and Faclon (1965) in which a profile of ripple bed z(x,t) was represented by a moving sinusoid of varying amplitude  $\eta(t)$  and a constant ripple length, a time dependent ripple length  $\lambda(t)$  is used in this study as follows:

$$\begin{split} z(x,t) &= s_{0}x + \eta(t) \sin \left\{ \frac{2\pi}{\lambda(t)} \left[ x - \int_{0}^{t} C_{r}(t) dt \right] \right\} \quad \dots \dots \dots (9) \\ \text{in which } x \text{ is the horizontal coordinate; } t \text{ is time; } s_{0} = \text{beach slope;} \\ C_{r}(t) \text{ is the celerity of ripple.} \end{split}$$

The growth rates of ripple height  $\eta(t)$  and ripple length  $\lambda(t)$  of Equation (9) are found from experimental results in a wave flume to be the same as

$$\eta(t) = \eta_{\max} \{ 1 - \exp \left[ -B^{*}(\frac{t}{T}) \right] \} \qquad (10)$$

and

$$\lambda(t) = \lambda_{\max} \{ 1 - \exp \left[ -B^{*}(\frac{t}{T}) \right] \} \qquad (11)$$

in which  $\eta_{\max}$  is the maximum height of ripple;  $\lambda_{\max}$  is the maximum length of ripple; B\* is the dimensionless growth of ripple; and T is the wave period. Information of geometry of equilibrium ripples has been provided by Vongvisessomjai (1984).

Sediment Transport Rate Due to Ripple Growth.- A simple rate of sediment transport  $q_r$  is determined only from ripple geometry developed from an initially straight bed excluding the information on ripple migration as

in which  $\beta$  is the porosity of sand on the bed. The maximum value of the above rate of sediment transport at time  $t_{max} = 0.693 T/B^*$  is

$$q_{rmax} = \frac{0.5}{\pi T} \gamma_s (1-\beta) B^* \eta_{max} \lambda_{max}$$
 (13)

Figure 1 shows an example of transient growth of ripple height, Eq. 10, and its corresponding sediment transport rate due to ripple growth, Eq. 12. Sediment transport rate due to ripple growth and migration will be presented as follows.

The celerity of ripple  $C_r(t)$  of Equation (9) is found from experiments to follow several patterns:

(a) a similar pattern to the growth rate of ripple as

 $C_{r}(t) = C_{rmax} \{1 - \exp[-C^{*}(\frac{t}{T})]\}$  .....(14a)



Figure 1. Transient Growth of Ripple Height and Its Sediment Transport Rate

in which  $C_{\rm rmax}$  is the maximum celerity of ripple and C  $^{\star}$  is the dimensionless migration rate of ripple.

(b) a growing-decaying pattern as

 $C_{r}(t) = At^{m} \exp (-Bt^{n}) \qquad (14b)$ in which A, B, m and n are empirical constants. (c) a constant celerity as  $C_{r}(t) = \overline{C}_{r} \qquad (14c)$ 

The rate of sediment transport per unit width  $q_s(x,t)$  can be expressed in terms of the ripple bed profile z(x,t) of Equation (9) as

The rate of sediment transport per unit width  $q_s(x,t)$  can then be determined from the above equation using the measured bed profile z(x,t) i.e. Equations 10 11 and 14a and a boundary condition of the instantaneous rate of sediment transport per unit width  $q_s(t)$ . These analytical solutions will be presented as follows.

Sediment Transport Rate Due to Ripple Growth and Migration.- Solving for  $q_s(x,t)$  by integrating Eq. 15 with respect to x where the bed profile z(x,t) is described by Eq. 9 yields

$$\begin{aligned} \mathbf{q}_{s}(\mathbf{x},t) &= \gamma_{s} \left[ \frac{\lambda}{2\pi} \left( \frac{\eta}{\lambda} \frac{d\lambda}{dt} + \frac{d\eta}{dt} \right) \cos \left\{ \frac{2\pi}{\lambda} \left( \mathbf{x} - \int_{0}^{t} \mathbf{C}_{r} dt \right) \right\} \\ &+ \left( \eta \mathbf{C}_{r} + \frac{\eta}{\lambda} \frac{d\lambda}{dt} \mathbf{x} - \frac{\eta}{\lambda} \frac{d\lambda}{dt} \int_{0}^{t} \mathbf{C}_{r} dt \right) \sin \left\{ \frac{2\pi}{\lambda} \left( \mathbf{x} - \int_{0}^{t} \mathbf{C}_{r} dt \right) \right] \end{aligned}$$

+ f(t) .....(16) The unknown function f(t) in the above equation has to be determine from a suitable boundary condition, i.e. at x = 0

 $\begin{aligned} q_{g}(o,t) &= q_{g}(t) \end{aligned} (17) \\ \text{Using the above boundary condition, Eq. 16 is} \\ q_{g}(x,t) &= \gamma_{g} \left[ \frac{\lambda}{2\pi} \left( \frac{\eta}{\lambda} \frac{d\lambda}{dt} + \frac{d\eta}{dt} \right) \left( \cos \left\{ \frac{2\pi}{\lambda} \left( x - \int_{0}^{t} C_{r} dt \right) \right\} - \cos \left\{ \frac{2\pi}{\lambda} \left( \int_{0}^{t} C_{r} dt \right) \right\} \right] \\ &+ \left( \eta \ C_{r} - \frac{\eta}{\lambda} \frac{d\lambda}{dt} \int_{0}^{t} C_{r} dt \right) \left\{ \sin \left\{ \frac{2\pi}{\lambda} \left( x - \int_{0}^{t} C_{r} dt \right) \right\} + \sin \left\{ \frac{2\pi}{\lambda} \left( \int_{0}^{t} C_{r} dt \right) \right\} \right\} \\ &+ \frac{\eta}{\lambda} \frac{d\lambda}{dt} x \sin \left\{ \frac{2\pi}{\lambda} \left( x - \int_{0}^{t} C_{r} dt \right) \right\} \right] + q_{g}(t) \qquad (18) \\ \text{The above } q_{g}(x,t) \text{ depends on } C_{r}(t) \text{ and } \int_{0}^{t} C_{r}(t) dt \text{ which are assumed as} \end{aligned}$ 

the following four cases:

Case	C <sub>r</sub> (t)	$\int_{0}^{t} C_{r}(t) dt$
I	0	0
II	$C_{rmax} \{1 - exp[-C^*(\frac{t}{T})]\}$	$C_{\text{rmax}}(t - \frac{T}{C} \{1 - \exp[-C^*(\frac{t}{T})]\})$
III	$-C_{\text{rmax}}\{1-\exp[-C^{*}(\frac{t}{T})]\}$	$-C_{\text{rmax}}(t - \frac{T}{C^*}\{1 - \exp[-C^*(\frac{t}{T})]\})$
IV	$C_{rmax} \sin (\frac{2\pi t}{\tau})$	$\frac{\tau c_{\text{rmax}}}{2\pi} \left[ 1 - \cos \left( \frac{2\pi t}{\tau} \right) \right]$

The resulting expressions of  $q_s(x,t)$  were present by Gunaratna (1984). The above four  $C_r(t)$  and  $\int_0^t C_r(t)dt$  are plotted as a function of time t in Figure 2, and their resulting sediment transport rates  $q_s(x,t)$  at times t = 15, 30 45 and 60 minutes are plotted in Figures 3a, 3b, 3c and 3d respectively using Sleath's Eq. 5 as boundary condition,  $q_s(t)$  of Eq. 17 or 18. The sediment transport rates due to ripple growth and migration,  $q_s(x,t)$  shown in Figures 3a, 3b, 3c and 3d used the same ripple growth of Figure 1, therefore, their rates of sediment transport can be compared.



Figure 2. Four Cases of Ripple Celerities and Their Integration





# EXPERIMENTATION AND RESULTS

Experimentation.- Experiments were conducted in the Hydraulic Laboratory of the Asian Institute of Technology. The major apparatus consisted of a wave flume ( $lm \times lm \times 40m$ ) with a flap-type wave generator, capacitance wave gauges connected to an amplifier and a chart recorder.

Various wave characteristics were tested on 1:20 and 1:10 slopes of medium sand  $(D_{50} = 0.41 \text{ mm})$  and on 1:20 slope of finer sand  $(D_{50} = 0.23 \text{ mm})$ . Wave profiles along the flume were recorded at the start, middle and end of each run while reading of sand accummulation in sand trap were made at 5 minutes, 15 minutes, 25 minutes, etc. Observations of ripples and bed profile changes were made at various locations along sloping beds at mean water depths h = 17, 27, 32, 37, and 42 cm at various time intervals. Table 1 lists the experimental condition which was plotted in Figure 4 as compared with the onshore-offshore criterion of Sunamura and Horikawa (1974) confirmed that most of the runs were onshore transports.

Run No.	Period T	Excentricity	Steepness	D <sub>50</sub>	Slope	g'yexpx10-
(	(s)	(mm)	H <sub>O</sub> /L <sub>O</sub>	(mm)	$S_0$ or tan $\alpha$	$(m^3/s/m)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	2 70	150	0 0075	0 41	1.20	8 98
2	2.46	150		0.41	1.20	4 44
3	2.40	150	0.0167			6.42
4	2.95	175	0.0062			10.63
5	2.43	175	0.0124		1	6.29
6	2.07	175	0.0197			9.43
7	2.96	200	0.0074	1		12.64
8	2.66	200	0.0096			9.76
9	2.44	200	0.0139			6.19
10	2 63	150	0.0075	0 41	1.10	4 47
11	2.29	150	0.0105	0.11	1.10	3.66
12	2.09	150	0.0130			0.75
13	2.90	175	0.0069	ł		-0.49
14	2.40	175	0.0100	1		1.82
15	2.01	125	0.0165	ļ		1.46
16	3.00	150	0,0148			3.34
17	2.75	200	0.0086			1.85
18	2.47	200	0.0107	[	ĺ	-0.36
19	2.03	125	0.0143	0.23	1:20	-0.58
20	2.98	125	0.0044		•	3.21
21	2,02	117	0.0134	1		-0.11
22	1.92	115	0.0127	[ '		-0.32
23	1.87	110	0.0122	l		-0.33
24	1.85	100	0.0020	1		0.00
25	1.86	90	0.0086	'		-0.08
26	2.06	120	0.0119			2.27
27	2.04	130	0.0132			1.18
				l	L	

TABLE 1.-Experimental Condition



Figure 4. Experimental Condition

Experimental Results.- Experimental data were then used to determine the growth rate of ripples B\*, the geometry of the maximum ripples,  $\eta_{max}$  and  $\lambda_{max}$ , and the celerity of ripples. Since a systematic pattern of ripple migration could not be obtained, the time average celerity  $\bar{C}_r$  and the maximum celerity  $C_{max}$  of ripple migration were presented. These obtained empirical results were found to correlate well with the densimetric sediment Froude number Fd\_\* =  $U_{1m}^2/[(s-1)gD]$  and the relative bed smoothness  $a_* = a_{1m}/D$ , in which  $U_{1m} = \pi H/[T \sinh(2\pi h/L)] =$  nearbed water particle velocity; H = wave height; h = mean water depth; L = wave length;  $a_{1m} = U_{1m}/\omega$  = nearbed amplitude of water particle excursion;  $\omega = 2\pi/T$  = wave angular velocity; T = wave period; s = relative density of sand with respect to water; g = gravitational acceleration; D = median diameter of sand. Denoting the obtained results (B\*,  $\eta_{max}/a_{1m}$ ,  $\lambda_{max}/a_{1m}$ ,  $\bar{C}_r/C$  and  $C_{max}/C$  where C = celerity of the surface wave) by Y, their relations with Fd\_\* and a\_\* are

 $Y = k \ Fd_{\star}^{1} a_{\star}^{1}$  .....(19) Table 2 summarizes the empirical constants k, i and j obtained from regression analyses. Most of j for medium sand equal zero implies that the obtained results are independent on  $a_{\star}$  but dependent on Fd<sub>\star</sub> only. Examples of these relationships for medium sand are shown in Figures 5-7 respectively for B<sup>\*</sup>,  $\eta_{max}/a_{lm}$  and  $\lambda_{max}/a_{lm}$ ,  $\overline{c_r}/c$  and  $c_{max}/c$ .

Parameter Y	Medium Sand (D = 0.41 mm)			Finer Sand (D = 0.23 mm)			
(1)	k (2)	i (3)	j (4)	k (5)	i (6)	j (7)	
в*	$1.77 \times 10^{-6}$	-0.394	1.68	$1.82 \times 10^{-4}$	0.432	0.366	
n <sub>max</sub> /a <sub>lm</sub>	0.464	-0.324	0	16.0	0.325	-0.951	
$\lambda_{max}/a_{lm}$	2.79	-0.328	0	60.6	0.183	-0.800	
ē <sub>r</sub> ∕c	$3.16 \times 10^{-6}$	1.25	о	$1.40 \times 10^{-6}$	0.271	1.22	
C'/C	$6.20 \times 10^{-6}$	1.25	0	$5.34 \times 10^{-7}$	0.717	0.500	









Sediment Transport Rate.- The averaged net sediment transport rates  $\mathbf{q}'_{vexp}$  measured in the trap at 5, 15 and 25 minutes as listed in Table 1 were found to be of the same magnitudes of those computed from ripple growth and migration. These measured transport rates were found to be about 30 to 60 per cent of the empirical rate, Eq. 8, for medium sand of Run Nos. 1-18 while they were about 5 to 30 per cent of Eq. 8 for finer sand of Run Nos. 19-27 which were in the ranges of transition and offshore transport shown in Figure 1.

Basing on the same growth rate of ripple, the sediment transport rate due to ripple growth,  $q_{rmax} = 2.4 \text{ N/m/s}$  as shown in Figure 1, was much smaller than that due to ripple growth and migration,  $q_s(x,t) \doteq \pm 20 \text{ N/m/s}$  for Cases II to IV and about equal to that of Case I with  $C_r = 0$  as shown in Figures 3a to 3d.

#### CONCLUSIONS

From this study of the trasient formation and migration of ripples, and the resulting sediment transport; the following conclusions could be drawn:

1. Growth rates of ripple height and length were found to follow the exponential form of Equations 10 and 11 respectively.

2. Celerities of ripple migration were found to have several patterns, Equations 14a, 14b and 14c, only the time averaged and maximum values were presented. More experiments would be required to quantify this phenomenon.

3. Empirical rate of sediment transport due to waves should be used with great care. Characteristics of ripple growth on a horizontal bed were rather uniform along the bed with negligible ripple celerity, therefore, the sediment transport rate should be negligible. However, a tray set into sediment bed would cause non-uniformity and thus traps a gross sediment transport forward and backward at either edge of the tray; this rate of transport of the mobile sediment could be calculated from expression for sediment transport rate due to ripple growth, Eq. 12.

4. On a sloping beach, characteristics of fluid, ripples and sediment transport rate were nonuniform and varied along the slope. Outside the breaker, the turbulence was smaller than that inside with less suspended sediment, the onshore transport rate here could be computed from the expression of sediment transport rate due to ripple growth and migration, Eq. 18.

# APPENDIX I.-REFERENCES

- Abou-Seida, M.M., "Bed Load Function Due to Wave Action," <u>Report HEL-</u> <u>2-11</u>, Hydraulic Engineering Lab., University of California, Berkeley, Calif., 1965.
- Bagnold, R.A., "Motion of Waves in Shallow Water, Interaction between Waves and Sand Bottom," Proceedings of the Royal Society of London, Series A, Vol. 187, 1946, pp. 1-15.
- 3. Dingler, J.R., "Wave Formed Ripples in Nearshore Sands," thesis presented to the University of California, at San Diego, Calif., in 1974, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

- Einstein, H.A., "Bed-Load Function for Sediment Transportation in Open Channel Flows," <u>U.S. Dept. Agric. S.C.S. Technical Bulletin No.</u> 1026, 1950.
- Grant, W.D. and Madsen, O.S., "Movable Bed Roughness in Unsteady Oscillatory Flow," Journal of Geophysical Research, Vol. 87, No. C1, 1982.
- 6. Gunartna, P.P., "An Analytical Model in Ripple Formation," thesis presented to Asian Inst. of Tech., Bangkok, Thailand, in 1984 in partial fulfillment of the requirements for the degree of Master of Engineering.
- 7. Inman, D.L., "Wave-Generated Ripples in Nearshore Sands," <u>Technical</u> <u>Memo No. 100</u>, U.S. Army Corps of Engineers, Beach Erosion Board, 1957.
- Jonsson, I.G., Wave Boundary Layers and Friction Factors, Proceedings of the Tenth International Conference on Coastal Engineering, Vol. 1, 1966.
- 9. Kalkanis, G., "Transportation of Bed Meterial Due to Wave Action, <u>Technical Memo. No. 2</u>, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1964.
- 10. Kennedy, J.F., and Falcon, M., "Wave Generated Sediment Ripples," <u>Report No. 186</u>, Hydrodynamics Laboratory, Massachusetts Institute of Technology, 1965.
- 11. Kobayashi, N., "Sediment Transport on a Gentle Slope Due to Waves," Proc. ASCE, Journal of the Waterway, Port, Coastal and Ocean Division, Vol. 108, No. WW3, 1982.
- 12. Madsen, O.S. and Grant, W.D., "Sediment Transport in the Coastal Environment," <u>Report No. 209</u>, Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Massachusetts Institute of Technology, 1976.
- Manohar, M., "Mechanics of Bottom Sediment Movement Due to Wave Action," <u>Technical Memo. No. 75</u>, U.S. Army, Corps of Engineers, Beach Erosion Boards, 1955.
- 14. Mogridge, G.R., and Kamphuis, J.W., "Experiments on Bed Form Generation by Wave Action," <u>Proceedings of the Thirteenth International</u> Conference on Coastal Engineering, Vol. 2, 1972, pp. 1223-1142.
- 15. Munasinghe, L.C.J., "Transient Ripple Formation and Resulting Sediment Transport," thesis presented to Asian Inst. of Tech., Bangkok, Thailand, in 1985, in partial fulfillment of the requirements for the degree of Master of Engineering.
- 16. Sleath, J.F.A., "Measurements of Bed Load in Oscillatory Flow," Proc. ASCE, Journal of the Waterway, Port, Coastal and Ocean Division, Vol. 104, no. WW3, 1978.
- 17. Sunamura, T. and Horikawa, K., "Two-Dimensional Beach Transformation Due to Waves," <u>Proceedings of the Fourteenth Conference on Coastal</u> Engineering, Vol. 2, 1974, pp. 920-938.
- Vongvisessomjai, S., "Oscillatory Ripple Geometry," Journal of Hydraulic Engineering, ASCE, Vol. 110, No. 3, 1984.
- Vongvisessomjai, S., "Sediment Transport under Oscillatory Flow," Proceedings of the Fifth Congress of Asian and Pacific Regional Division, Int. Assoc. for Hyd. Research, Seoul, Korea, 1986.