# Wave Effects on Mega Ripples and Objects on a Sandy Seabed

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## LONG-TERMS GOALS

Our general goals are to advance the hydrodynamics of waves, currents and the two-phase dynamics of sediment transport in coastal seas. An important part is to gain physical understanding of the physics and to enable quantitative prediction of the seabed evolution near the shore. The nearshore morphology includes features of a wide range of length scales : from the entire beach to sand bars and down to sand ripples, The mechanisms may differ over different scales, and may also be intertwined. This proposal focusses on the formation of mega ripples on a sandy seabed under sea waves.

## OBJECTIVES

We are extending past theoretical works on ripples under purely oscillatory flows (i.e., waves of infinite length) by Blondeaux &d Vittori (1990, 1991) for partially standing waves by Mei & Yu (1997), and recent work on sandbars under waves of finite length byYu & Mei (2000) to the evolution of mega-ripples under more complex waves, with and without a rigid object. Emphasis will be on the finite wavelength and the complex wave pattern, and on the combined effects of both bed load and suspended load. This year we have been working on the following two aspects

1. Initial instability of mega-ripples.

2. Nonlinear evolution and migration of mega-ripples in progressive waves.

We are starting

3. Nonlinear evolution and migration of mega-ripples on bars in partially standing waves.

The last aspect will be started in the next fiscal year.

4. Interaction of a cylinder with mega-ripples.

## APPROACH

We are focussing our attention to the coastal zone where the typical length scales are: water depth 5~10 m; sea wave length 100 m; seawave amplitude 1 m; wave boundary layer thickness 1 ~ 10 cm ; sand ripple wavelength 10 cm ~ 1 m; sand ripple amplitude 1 ~ 10 cm. Accordingly we assume that both surface waves and ripples have small slope: $O(KA) = O(ka) = O(K/k) = O(\varepsilon) << 1$.

Because the magnitude of the eddy viscosity is uncertain we are now considering the general case where the wave boundary layer range from very thin : $a/\delta << 1$ to very thick, $a/\delta = O(1)$ where $a$ is the typical ripple amplitude and $\delta$ the boundary layer thickness.

***Fluid flow***: We have started a two dimensional theory in which waves crests and the ripples crests are straight and parallel. We are now extending the theory of Blondeaux (2000) for purely progressive waves to partially standing waves. Our approach is to obtain first the flow field in and outside the boundary layer above the ripples. Constant eddy viscosity model is adopted for analytical simplicity. The stream function is expanded as a perturbation series in powers of the ripple (or wave) steepness $\varepsilon$. The fluid velocity is required to vanish on the ripple surface below and to match the velocity field of the potential waves above. It is then found that at the leading order the boundary layer flow is that of the Stokes. At the second and third orders the flow field including the mass transport (Eulerian streaming) is affected by both the relatively long waves and the relatively short ripples. The boundary layer flow field is then used to compute the fluid shear stress on the top of the sandy surface.

***Sediment transport*** : We start from the conservation of sand mass,

$$(1-n)\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = 0 \tag{1}$$

where *n* denotes the porosity*, h* the ripple height about the mean seabed and *q* the rate of sediment discharge. So far we only include the bed-load transport and employ the following empirical formula relating the sand discharge *q* and the modified Shield parameter $\theta$, i.e.,

$$q = a\left(\frac{s-1}{s}\right)\left(\frac{\sqrt{(s-1)gd}}{\nu}\right)^{c}\theta^{b} \qquad where \quad \theta = \frac{\tau}{\rho(s-1)gd} - \beta\sin\left(\tan^{-1}\left(\frac{\partial h}{\partial x}\right)\right) \tag{2}$$

where $a, b, c$ are empirical constants. Note that $\theta$ is the sum of the effects due to bed shear stress $\tau$ and the effect of gravity related to the slope(since gravity tends to pull sediments down a sloping surface).

We then carry out a perturbation analysis for small $\varepsilon$. Let the leading order ripple height be sinusoidal,

$$h = C(x_1, t_1, t_2)e^{ikx} + c.c. \tag{3}$$

Then we find after the first two orders $O(\varepsilon)$ and $O(\varepsilon^2)$,

$$\frac{\partial C}{\partial t} - (E_1 + i\varepsilon E_2)C = 0 \tag{4}$$

where $E_1$ and $E_2$ are both real. First $E_1$ governs the stability of ripples and is affected by two competing factors: (i) the bed shear stress which renders $E_1$ positive, hence is destabilizing, and (ii) gravity which renders $E_1$ negative, hence is stabilizing. The threshold of instability depends on the Reynolds number and particle size.

## COMPLETED RESULTS

A typical numerical result on the instability threshold is shown in Figure 1.a,b. Instability is found to start sooner for higher Reynolds number (stronger) waves, and finer sand, i.e., or larger sand Froude number

$$F = \frac{U}{\sqrt{(s-1)gd}} \tag{5}$$

where $d$ is the sediment diameter,. The growth rate is, to the leading order, independent of the surface wave length.

The factor $E_2$ contributes to the propagation velocity for the ripple. So far we have just finished the computation for the ripple advance velocity under a pure progressive wave. Our numerical results confirm those of Blondeaux (2000) that the ripple advance velocity increases with wave Reynolds number and inversely with the wave length. Thus under stronger or shorter surface waves ripples advance faster waves. A sample result is shown in Figure 2. The ordinate is the migration velocity normalized by K (surface wavenumber) times $\nu$ (viscosity). The abscissa is th Reynolds number equal to A/$\delta$ where A is the wave amplitude and $\delta$ the boundary layer thickness. New experiments are planned.

## IMPACT

This result will enable us to predict the sediment transport rate by ripple migration, once the ripple profile is found later from a later nonlinear theory.

## WORK PLAN FOR FY2002

**Two dimensional partially standing waves:**

a. **Ripple migration velocity**: In the next two months we shall calculate and examine the ripple phase speed under partially standing wave with finite reflection coefficient $0 < R < 1$. We shall find out how the ripple phase speed varies under the surface wave envelope. In particular, do ripples advance faster under the nodes and slower under the antinodes?

b. **Ripple amplitude and sediment transport rate**: By extending our perturbation analysis to order $O(\varepsilon)^3$ we expect the evolution equation of the ripple amplitude to be nonlinear and of the form

$$\frac{\partial C}{\partial t} - EC + \alpha \frac{\partial C}{\partial x} + \beta |C|^2 C - \kappa \frac{\partial^2 C}{\partial x^2} = 0 \tag{6}$$

The dependence of coefficients $E, \alpha, \beta$ and $\kappa$ on the local wave properties, hence on the spatial location, will be worked out. Afterwards the growth of ripple amplitude at any $x$ will be solved as an initial value problem with periodic boundary conditions. From, the ripple profile we shall compute and examine the sediment transport rate as the consequence of ripple migration.

c. **Laboratory experiments**: We plan to conduct laboratory experiments in an existing plexi-glass flume 15 ft long, 1ft by 1 ft cross section. Fine sand will be spread over the entire length of the flume.

Standing waves will be generated in the wave flume and the evolution of ripple height and wavelength will be measured as a function of time and space, for a range of reflection coefficients and wave frequencies.

**Three dimensional motion due to short-crested waves**

According to the general theory of mass transport under three dimensional wave motion is known (Mei, 1989, chap. 10), an obliquely incident and reflected wave system near a seawall would induce sediment accumulations and excavations, resulting in a horizontally periodic pattern. Jan and Lin (1998) have reported experimental records of complex patterns in a large wave basin where waves are obliquely incident to and reflected by a straight and vertical seawall along the *x* axis. Three angles of incidence were tested : 30, 45 and 60 degrees from the *y* axis. The wave surface is of the simple form:

$$\varsigma(x,y,t) = A\cos(2\pi y / L_y)\exp(2\pi i(x / L_x - \omega t)) \tag{7}$$

where $L_x, L_y$ represent the wavelength components in the x and y directions. and Figure 3 showing the bed forms from Jan and Lin are reproduced here. Note that there are distinct bands of three types of ripples. Three distinct bed forms can be seen in three bands. Type A ripples which have crests parallel to the y axis, appear along the anti-nodal lines $y / L_y = 0, 1/2, 1, ...$ where $\cos(2\pi y / L_y) = \pm 1$ and the fluid velocity is to and fro along the x axis like a progressive wave. Type C ripples which have crest parallel to the x axis appear along the nodal lines $y / L_y = 1/4, 3/4, 5/4......$ where $\cos(2\pi y / L_y) = 0$ and the fluid velocity has a component to and fro along the y axis as near a nodal line of a standing wave. In intermediate regions where the local fluid velocity field is more complex, the bedforms of Type B appear which look like honeycombs, islands or lakes!

Our next goal is to extend the theory from two to three dimensions. In particular we shall derive the extension of Eq. (6) to include variations in both x,y directions. The bedform instability then depends on the local flow field. While the Types A and C are essentially two dimensional we shall aim at quantitative prediction of Type B using the techniques of nonlinear hydrodynamics instability for Benard cells.

**PERSONNEL**

Two graduate research assistants will take part in the project. Mr. Yile Li a PhD candidate in Ocean Engineering has been developing the theory. Mr. Blake Landry, who just arrived on September 1, 2001will begin a MS thesis study on experiments, with support largely from an existing ASSERT grant.

**RELATED PROJECTS**

ONR N00014 90-J-3128 Dr.T. Swean, Wave-induced transport to sediments.

**PUBLICATIONS**

Mei, Hara and Yuhi, 2001 Longshore bars and Bragg Resonance. *Geomorphological Fluid Mechanics*, Springer –Verlag, edited by A.Provencale, and N. Balmforth, in press

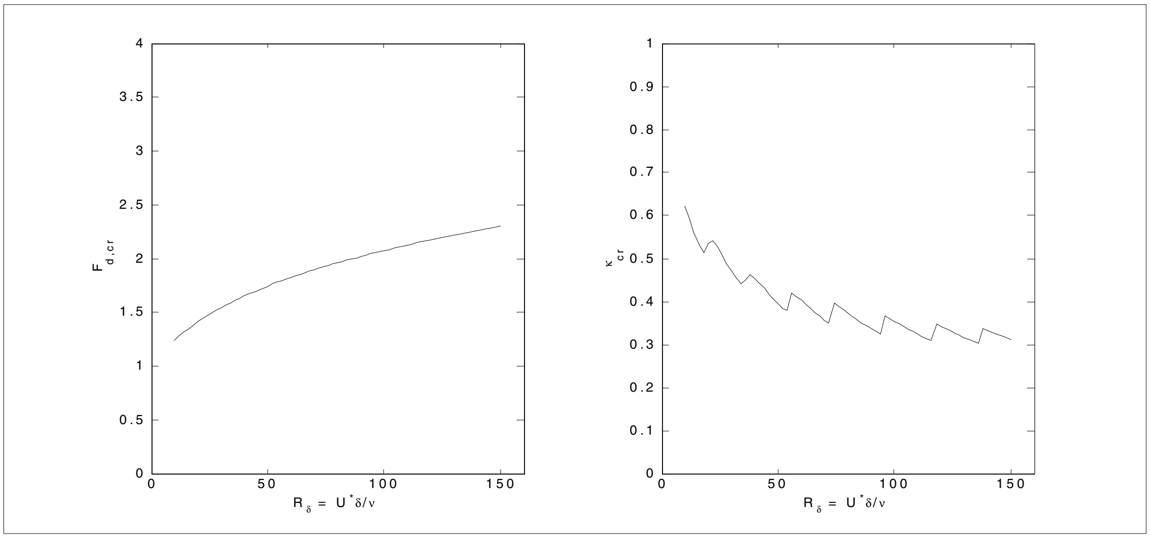


***Figure 1. Threshold instability for purely progressive waves***
***left: particle Froude number $F_{d,cr}$; right: threshold ripple slope $\kappa = k\delta$***

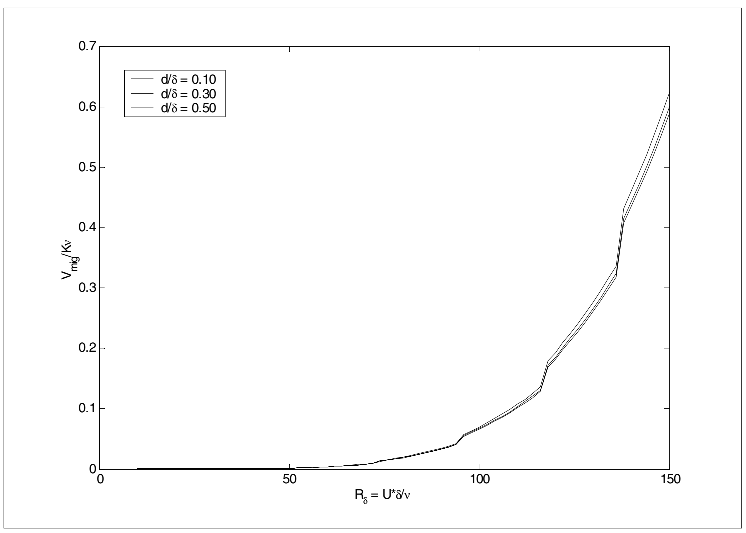


***Figure 2. Nondimensional migration velocity $V_{mig}/K\nu$***

***s = 2.65, KH = 0.5, $\omega = 0.8$***

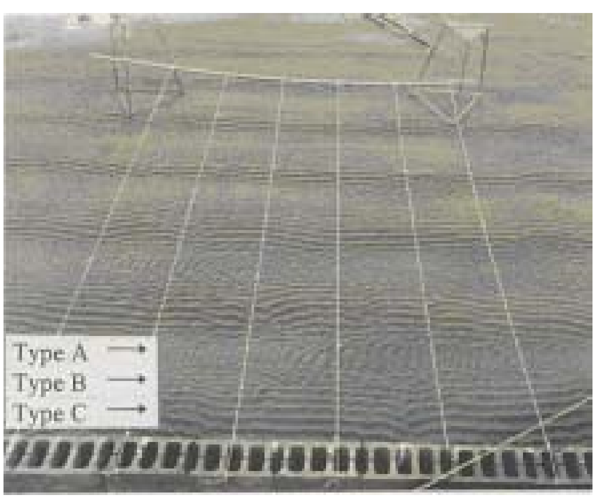


***Figure 3. Sand bed pattern produced in laboratory by oblique standing wave ($\theta$ =30°, T=1.1s, H=7.5cm)***

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Mei, C. C., & Yu, J., 1997 Note of the instability of sand ripples under partially standing waves *Phys Fluids* 9, 2379-2395.

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