

The Dynamics of Cobbles in and Near the Surf Zone and Mine Movements in and Near the Surf Zone

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LONG-TERM GOALS

The long-range goals of this research are to develop, by laboratory experimentation, theoretical analyses and comparisons with field observations, a basic understanding and, eventually, a predictive capability of the behavior of large bottom particles (cobbles) in the shoaling, wave-breaking and swash zones. Here, the size classification of cobbles used by the American Geophysical Union as particles in the diameter range 6.4 to 25.6 cm is employed. Disk-shaped anti-tank mines are of similar size.

OBJECTIVES

The scientific objectives for this research are directed toward better understanding the motion and burial/scouring of cobbles on beaches which (a) are impermeable with various characteristic roughness and (b) are permeable with sand bedforms that are free to vary with time and with flow characteristics.

The objectives for the impermeable floor case are to (i) develop proper parameterizations for the background velocity field in the shoaling, wave-breaking and swash zones; (ii) use this parameterization to extend the models previously developed for time-dependent flows to include the space and time-dependent surf zone; (iii) obtain data on the transport of cobbles in the entire wave-tank surf zone and test the model against the experimental data.

The objectives for the permeable sandy floor case are directed to better understanding (i) the large time dynamics of sand ripples, formed in periodical flow, and (ii) the process of burial/scouring of cobbles on a sandy beach with ripples in such periodical flow. In particular, we wish to study (i) the evolution of an initially flat sandy bottom; (ii) the long-time behavior of the bottom topography and (iii) the eventual long-time fate of the model cobbles.

APPROACH

Carefully designed laboratory experiments are the key to achieving the scientific goals delineated above. These will be conducted in the Arizona State University wave tanks that were designed, developed and tested with the support provided by the present grant. One of the wave tanks (104.5 x 3 x 6 ft) includes a computer-controlled wave maker at one end and a sloping beach at the other; the facility can accommodate solid as well as sandy beaches. The second smaller tank operates using

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standing waves of large amplitude. Acoustic-Doppler velocimetry (ADV) and other standard methods will be used to determine the mean and turbulent background flow characteristics. Cobble motions will be monitored by employing video cameras and the resulting data will be analyzed using standard software. Basing on the results of experiments, proper theoretical models will be developed and tested.

Coupled with the laboratory observations of the background velocity field in the shoaling, wave-breaking and swash zones, we will apply theoretical arguments to delineate proper parameterizations of the background velocity field for the case of an impermeable bottom. Furthermore we will employ these parameterizations to refine and extend the models for cobble motions developed under the present grant for the swash (Luccio et al., 1998) and shoaling (Voropayev et al., 1998) zones.

WORK COMPLETED

The behavior of large and heavy disk-shaped bottom particles of diameter D (= 5-15 cm), height H (= 3-8 cm) and density ρ_c (= 1.6-2.5 gmcm⁻³) placed on a sandy bottom (mean sand diameter d = 0.04 or 0.1 cm, density ρ_s = 2.65 gmcm⁻³) in a wave induced oscillatory flow was reproduced in laboratory wave tank. In the case of a sandy bed, the bottom itself becomes movable and two processes may occur. First, if the fluid velocity is high enough, sand ripples may be formed at the bottom (see, e.g., Sleath, 1984), and the height h of the ripples may be comparable with the cobble height H . Because of large time instabilities, the bottom topography does not reach an exact steady state and slow variations in the positions of ripples are possible. The slow drift of the ripples may lead to the periodical burial of large and heavy bottom particles. This process has not been studied in detail previously and thus a series of experiments on the dynamics of the formed sand ripples and the influence of this process on the behavior of large bottom particles (cobbles) was conducted. Furthermore, at moderate values of the fluid velocity, when no significant ripples are formed, one may expect that the presence of relatively large objects can modify the flow; thus noticeable scouring in the vicinity of cobbles is possible, which may result in (at least partial) burial or subsidence of cobbles (see, e.g., Herbich et al., 1984).

Model cobbles were placed on the sandy bottom and their subsequent motion, the temporal evolution of the sandy bottom profile and the velocity field in water were observed. Particular attention was paid to the large time behavior of such a system. A simple model was developed to explain the results of observations. The model includes such external parameters as the size and density of the cobbles, the sand characteristics and the amplitude and frequency of the waves.

RESULTS

So far this year, our research has concentrated on cobble behavior in the presence of the sandy coastal floor, which is free to move in a periodic flow. The principal outcomes to date are as follows. (i) When the background velocity is just below its critical value, small-scale rolling grain ripples develop on an initially flat bottom and noticeable scour around the cobble occurs. (ii) At large times the scour pattern reaches a quasi-steady state and the resulting maximum subsidence S becomes equal to

$$S = \text{Const } D$$

(Const = 0.15). (iii) When the background velocity exceeds its critical value, the vortex ripples start to form.

Typical time $\tau = C/\omega\psi^{1/2}$ ($C = 2500$) of ripple formation depends on the wave frequency ω and the mobility parameter ψ (Fig. 1). After the time 2τ a regular quasi-steady system of ripples is formed (Fig. 2a) with one ripple across the cobble (Fig. 3a) and the cobble partly or completely buried (depending on the ripple size h and cobble height H). (iv) At larger times $t > 2\tau$ the system of ripples is not stable (Figs. 2b, 3b) and every ripple slowly migrates with some mean drift velocity which can be estimated as

$$U_d = U_0 \psi^{1/2} (2.2 - 0.345 \psi^{0.34}) / 8C,$$

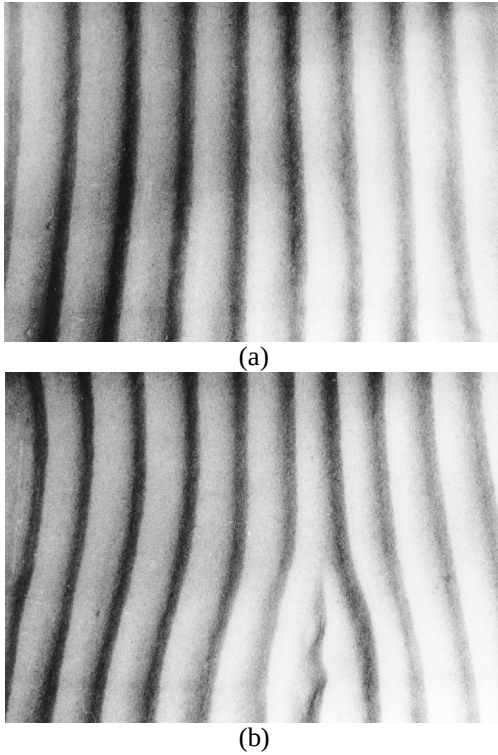


Figure 2. Top view photographs showing a regular system of ripples in steady oscillatory flow (a) and the large time instability and formation of a new ripple (b). With time the newly formed ripple spreads across the flow and initiates small mean drift of the surrounding ripples.

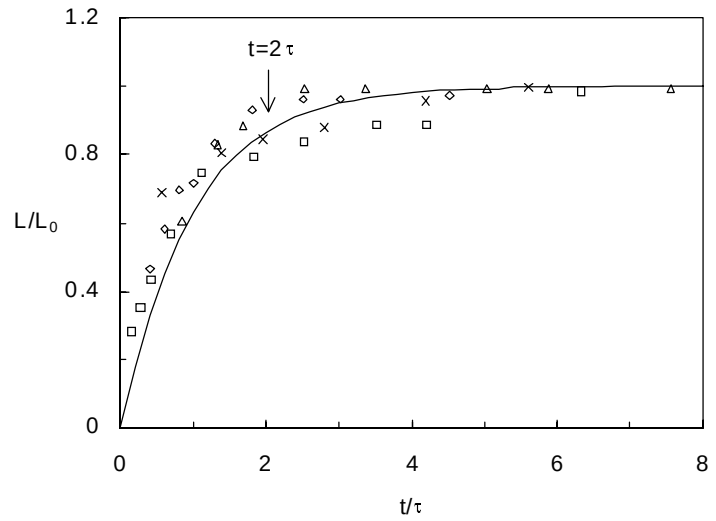


Figure 1. Non-dimensional ripple lengths L/L_0 as functions of non-dimensional time t/τ for four different experiments (symbols). Solid line shows the approximation function $L/L_0 = 1 - \exp(-t/\tau)$.

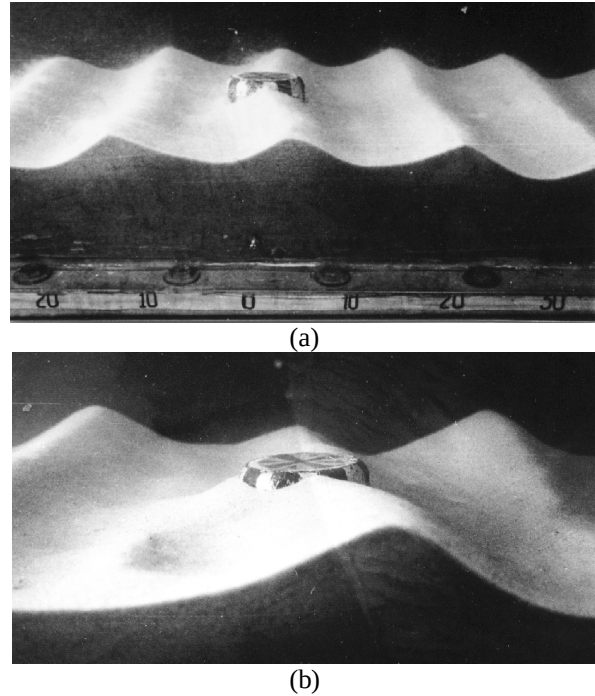


Figure 3. Side view photographs showing cobble on sandy bed in oscillatory flow: (a) after time $t \approx \tau$ a regular system of relatively small ripples, the size of which slowly increased with time (see Fig. 1), develops on initially flat bottom with one ripple across the cobble, (b) initiation of large-time instability (close view). Scale is given in cm.

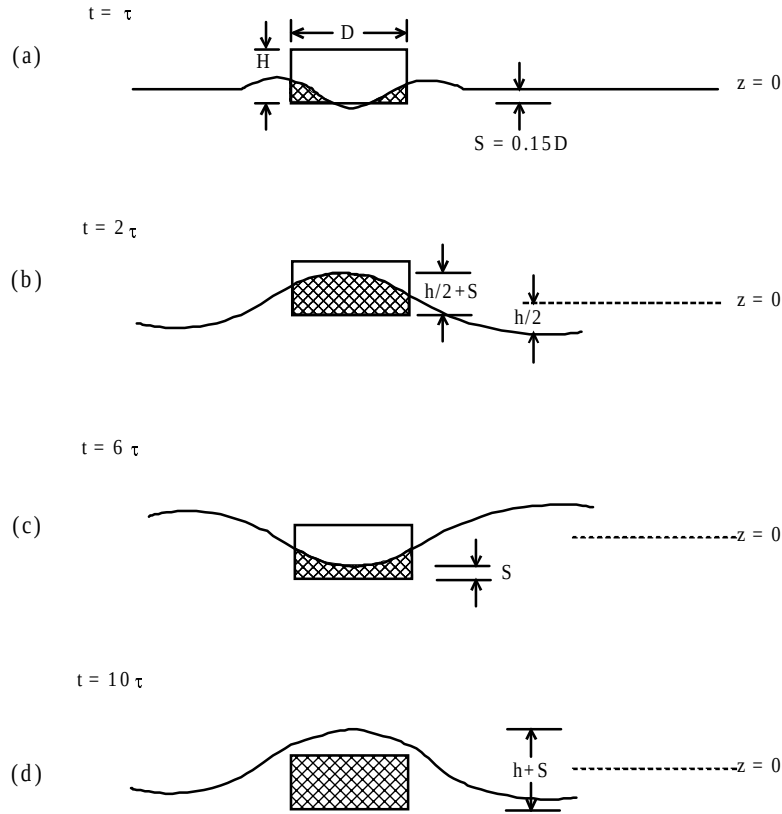


Figure 4. Schematic showing the time behavior of a cobble, which was placed on a flat sandy bottom in a steady oscillatory flow: (a) local scour and subsidence of cobble at relatively short time, (b-d) periodical burial of cobble at large time.

where $U_0 = \omega \varepsilon$ and ε is the amplitude of the fluid displacement. As a result a heavy cobble appeared to be periodically near the crest or valley of a ripple thus being buried periodically (Fig. 4).

The estimates for the typical oceanic conditions show that because of the large time instability of bottom topography a cobble at a sandy bed may be completely buried after 4-10 hours. The main results are reported in Voropayev et al. (1998a,b).

IMPACT/APPLICATIONS

The motion of "heavy particles", such as cobbles, relative to boundaries such as sandy beaches in the presence of oscillatory and turbulent background flows is not well understood from a fundamental point of view. The present project is an integrated laboratory, theoretical and field program that seeks to better understand this complex physical problem.

TRANSITIONS

Discussions between Dr. Todd Holland from the Naval Research Laboratory and project personnel at Arizona State University are being held to develop information based on this research that can be transitioned to the Navy.

RELATED PROJECTS

This project is linked to a field observational and modeling program being carried out by personnel of the Naval Research Laboratory (NRL) at the Stennis Space Center under the direction of Dr. Todd Holland. Close collaboration between the laboratory and theoretical studies at Arizona State University and the mine-motion observation and modeling studies of NRL is being effected. Dr. Holland will spend some time each year at ASU to cooperate in the research effort. He will also serve on the committees of ASU research students working on this project.

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