The Dynamics of Cobbles in and Near the Surf Zone

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Grant Number: N00014-95-1-0543
http://www.eas.asu.edu/~pefdhome/efdfamily.htm

LONG-TERM GOALS

The long-range goals of this research are to develop, using laboratory experiments, theoretical and, in some cases, numerical analyses and field observations, a basic understanding and, eventually, a predictive capability of the behavior of large bottom particles (cobbles/mines) 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 comparable size and density.

OBJECTIVES

The scientific objectives of this research are directed toward better understanding the behavior of cobbles on beaches, which are permeable with movable sand bedforms. These objectives will permit a better understanding of (i) the long-time dynamics of bottom topography including sand ripples and bars formed in a model surf zone, and (ii) the processes related to periodic and permanent burial of cobbles on a sandy beach with ripples and bars in time- and space-dependent surf-zone flow. In particular, we wish to study (i) the evolution of an initially flat sandy beach; (ii) the long-time behavior of the bottom topography, and (iii) the behavior of model cobbles.

APPROACH

Carefully designed laboratory experiments are the key to achieving the stated scientific goals. The experiments are conducted using a large (32 x 1.8 x 0.9 m) wave tank located at Arizona State University. The tank is equipped with a computer-controlled wave maker and a sloping beach. The background flow characteristics are measured using Acoustic Doppler velocimetry (ADV), particle image velocimetry (PIV), wave gauges, traversing platforms, data acquisition systems, and other standard methods. The change in bottom topography and cobble behavior are monitored by employing video cameras and the resulting data are analyzed using in-house developed software.

WORK COMPLETED

This work is a continuation of our previous studies (Lucccio et al, 1998: Voropayev et al., 1998; 1999; 2001) where, as a first step, horizontal and sloping solid impermeable beaches with artificial roughness

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **The Dynamics of Cobbles in and Near the Surf Zone**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Arizona State University,,Department of Mechanical and Aerospace Engineering,,Tempe,,AZ, 85287**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

were used. In the present study a homogeneous layer of sand was placed on the slope, which significantly complicated the problem (see, e.g., Blondeaux, 1990, 2000). To achieve the scientific goals formulated above, experiments were conducted in the ASU wave tank. In these experiments the evolution of an initially flat sandy beach as well as the processes of ripple and sandbar formation and their dynamics in time and space-dependent surf-zone flow were studied. Quantitative data on the background flow characteristics, changes of bottom topography and the behavior of cobbles were obtained using high-resolution video cameras, a three-component acoustic Doppler velocimeter and other standard techniques. Physical explanations of the results obtained were also advanced.

RESULTS

Our research during FY 01 concentrated primarily on bottom topography transformation under conditions similar to those occurring in a shoaling surf zone with a sandy slope and the associated cobble burial/exposure.

When the fluid velocity exceeds a critical value along an initially flat sandy slope (Fig. 1 a), the initiation of sediment motion takes place and ripples start forming. The ripple formation is not uniform along the slope. Rather, ripples are first generated just offshore of the breaking point where the water velocity amplitude (and mobility parameter) has its maximum. These first ripples form a front propagating in the offshore (down-slope) direction (Figs. 1 b, c). As the front moves offshore, the water velocity decreases (due to the increase in water depth) and the time τ necessary for ripple formation increases (Voropayev et al., 1999). As a result, the ripple front propagation velocity decreases. When the ripple front arrives at the location where the flow velocity is equal to the critical velocity for initiation of sediment motion, it stops.

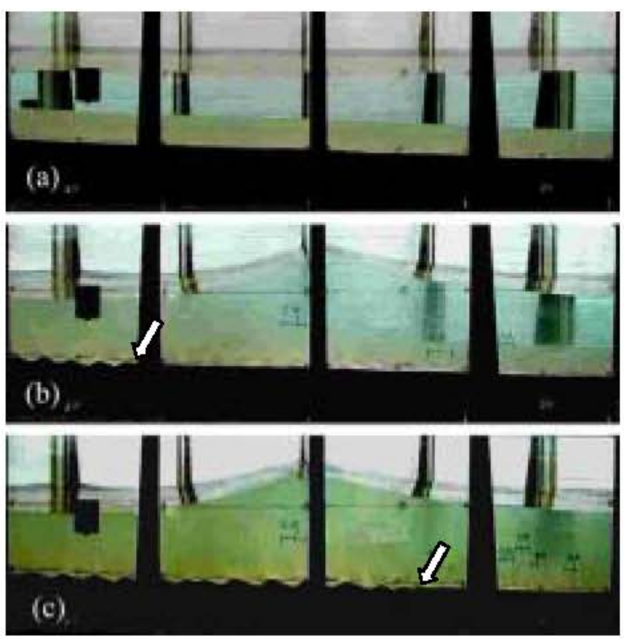

Figure 1. Ripple front (shown by arrow) propagating along initially flat slope (a) in the offshore (from left to right) direction. Wave frequency $\omega = 0.4$ Hz, paddle excursion $2\varepsilon_0 = 15$ cm, (a) t = 0, (b) 3, (c) 10 min.

Experimental data on the front propagation were collected and explained using a model developed by the present investigators. The underlying concept of the model is that the ripple height h increases with time t as $h/h_0 = 1 - \exp(-t/\tau)$, where h_0 (equilibrium ripple height) and τ vary along the slope in accordance with the background flow variation (h_0 increases and τ decreases in the offshore direction). Typical example showing comparison between the measured and calculated values for the ripple front position along the slop as function of time is given in Fig. 2. Note that for a spatially homogeneous flow on a horizontal bottom the ripple front propagation velocity has no sense because it goes to infinity.

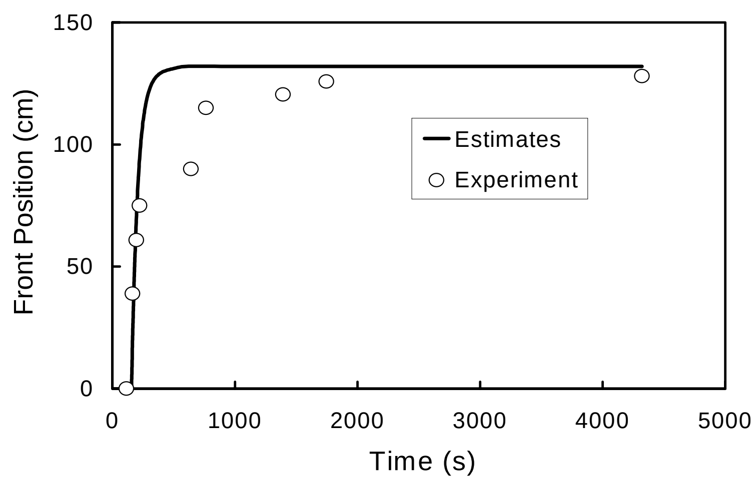

Figure 2. Comparison of the front positions as measured (points) and estimated by the model (solid line), ω = 0.4 Hz, $2\varepsilon_0$ = 10 cm.

After the ripples have formed they reach a state of quasi-equilibrium with their established characteristics depending on the slope position. A model that allows one to estimate the established ripple length L_0 and height h_0 as well as characteristic time τ along the slope is proposed and compared with observations.

Because of the instability, ripples migrate along the slope (Fig. 3) with a drift velocity that depends on the slope position. In contrast to the case of horizontal bottom, where the drift velocity has only a stochastic component (which has no preferred direction and averaged over large times tends to be zero, Voropayev et al., 1999), on a slope the drift velocity U_d has two components, stochastic U_d' and unidirectional U_d''. The model proposed permits the estimation of both of these components and a typical example showing a comparison between the measured and estimated values for the drift velocity is given in Fig, 4. Although some differences can be seen at small transport rates, the general agreement between the experimental data and the estimated values for the net drift is satisfactory at higher transport rates.

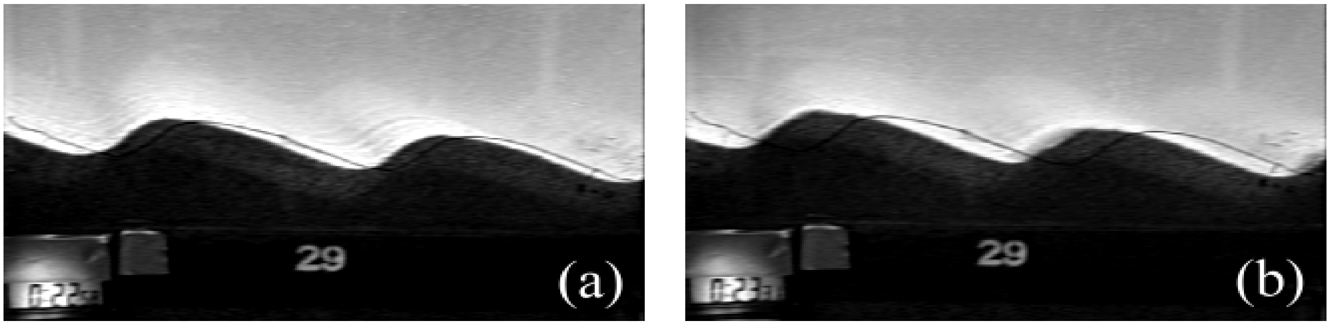

Figure 3. Large ripples migrating in the onshore direction (from right to left). Solid line shows the ripple position at t = 0, ω = 0,4 Hz, 2ε_0 = 9 cm, (a) t = 3, (b) 10 min.

In order to better understand cobble-sandbar interactions, experiments were conducted on the formation and evolution of sandbars on an initially flat sandy slope. In the range of parameters used in experiments at least two different types of sandbars were observed, namely onshore moving sandbars and offshore moving sandbars. It is shown that at large times the onshore moving sandbar becomes unstable and transforms onto a mixed type sandbar. The main factors affecting the type of the formed sandbar are the breaker type and the related sediment transport.

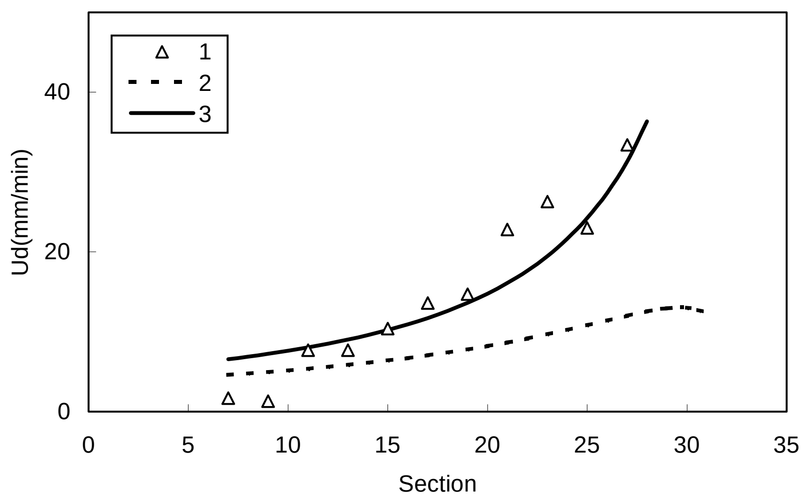

Figure 4. Ripple drift velocity as a function of the along slope position, ω = 0.4 Hz, 2ε_0 = 20 cm, t = 120 min. Symbols - measured values of the net drift velocity U_d, dashed line - estimated values of the stochastic component U'_d, solid line - estimated values of the net drift velocity $U_d = U'_d + U''_d$.

For the experiments with a spilling breaker, offshore moving sandbars were formed. In this case, even after breaking, waves are still energetic enough to form a large vortex onshore of the accumulated sand, which causes offshore sediment motion. This adds to the sediment transported by the onshore migrating ripples in the region offshore of the sandbar. As a result, an offshore moving sandbar with a bump-like structure is formed. The evolution of a typical offshore moving sandbar is shown in Fig. 5. First, ripple formation takes place on an initially flat sandy slope. When these ripples reach their equilibrium state, they start migrating onshore. Sediment transported by the ripple migration accumulates at the onshore side of the wave-breaking point. As soon as accumulated sand reaches a critical size, a large coherent vortex, generated by still energetic flow after the spilling breaker, starts forming on the onshore side of the growing sandbar. This vortex digs the onshore side of the sandbar causing an offshore movement of the sandbar. At the same time, the drifted ripples, which have moved onshore, add sediment to the offshore side of the sandbar. The steepness of both the onshore and offshore sides of the sandbar increases and sandbar takes a bump-like form.

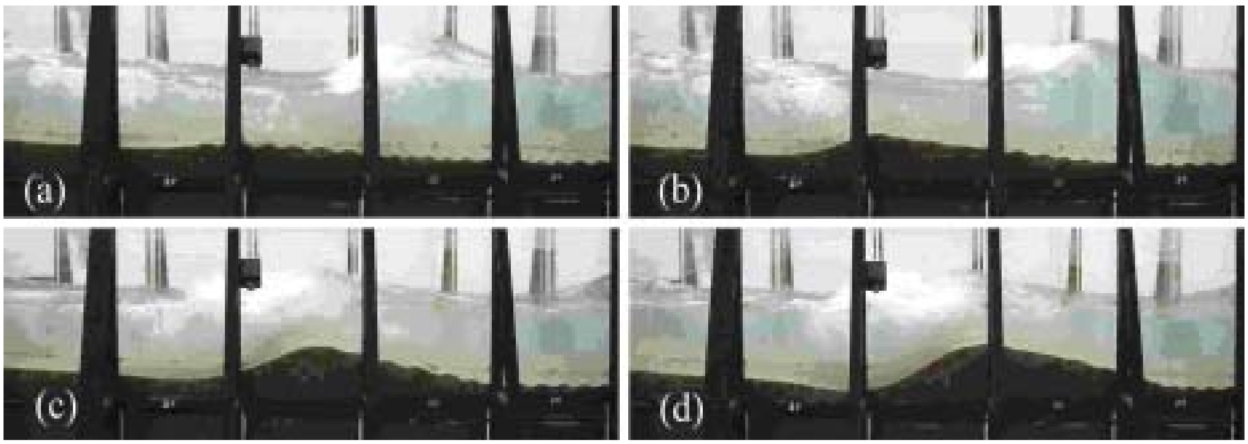

Figure 5. Formation of a sandbar moving offshore with ripples under spilling breaker on initially (t = 0) flat bottom and bar evolution with time, (a) t = 50, (b) 75 (c) 110, (d) 150 min.

For the experiments with a plunging breaker, onshore moving sandbars were formed. The plunging breaker occurs closer to the shoreline and a significant amount of energy is dissipated by a large vortex. The flow is not sufficiently energetic to form another large vortex on the onshore side of the accumulated sand. As a result, mean onshore sediment transport takes place and an onshore moving sandbar forms. These sandbars are smaller in height but larger in length. Their tops are considerably flat and they start increasing the local beach slope and decreasing the water height after they have moved onshore (Fig. 6 a). At large times, however, such a sand bar becomes unstable and splits onto two bars moving onshore and offshore (Fig. 6 b). It occurs because there is a continuous feedback mechanism between the sandbar type and wave breaker type and its location. Initially, an onshore moving sandbar was formed by the plunging breaker; however, the location of the breaker is not fixed due to the change in the bottom topography and other effects such as wave reflection caused by the forming sandbar. At larger times, when the plunging breaker location moves onto the top of onshore moving sandbar, large coherent vortex due to the breaking starts splitting the initial sandbar onto onshore and offshore moving sandbars as shown in Fig. 6 b.

Figure 6. Onshore moving sandbar under plunging breaker. (a) t = 75, (b) 170 min after beginning of the experiment.

More energetic shorter waves (spilling breakers) generate offshore moving sandbars and expose mines close to shore and cause burial of mines further offshore. Less energetic longer waves (plunger breakers) generate onshore moving sandbars with the reverse effect and cause burial of mines close to shore and expose mines further offshore.

IMPACT/APPLICATIONS

The influence of short time and long time changes in the bottom topography on the behavior and burial of large heavy "particles", such as cobbles/mines, on a sandy beach submerged in a periodic spatially dependent flow typical of a surf zone is not well understood from a fundamental point of view. This project has made significant advances in this regard by utilizing integrated laboratory and theoretical approaches. and field program (carried out by NRL) that seeks to better understand this complex physical problem.

TRANSITIONS

To develop a knowledge base that can be transitioned to the Navy, we maintain close contacts with Dr. Todd Holland from the Naval Research Laboratory with regard to studies on cobble/mine dynamics in a surf zone.

RELATED PROJECTS

This project is linked to a field observational and modeling program that was carried out by personnel of the NRL at the Stennis Space Center. Our project is also linked to another laboratory modeling program that is being funded by the ONR Marine Geosciences Program (PI: Dr. H. Fernando). This latter project also has close ties with NRL personnel at the Stennis Space Center and deals with large non-walking mines in the shoaling coastal zone.

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