THE DYNAMICS OF COBBLES IN AND NEAR THE SURF ZONE

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Award#: N00014-95-1-0543
and

MINE MOVEMENTS IN AND NEAR THE SURF ZONE

Award#: N00014-97-1-0616

GOAL

The long-range goals of this research are to develop, by laboratory experimentation, theoretical analyses and comparisons with field experiments, a basic understanding and, eventually, a predictive capability of the motion of 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).

OBJECTIVES

The scientific objectives established for the next several years are directed toward better understanding the motion of cobbles on sloping beaches which (a) are impermeable (with various characteristic roughnesses) and (b) are permeable with bedforms that are free to vary with time. 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) obtain data on the drag, lift and friction forces acting on a cobble which is subjected to the action of a periodic shear flow with simultaneous onshore and offshore velocities at certain phases of the motion and having layer thicknesses comparable to the thickness of the cobbles (as in the swash zone) and, similarly, for a periodic flow for which the fluid depth is much greater than the thickness of the cobbles (as in the shoaling and wave-breaking zones); (iii) use of the parameterizations obtained in (i) and (ii) to extend the models previously developed for simplified time-dependent flows to include the entire space- and time-dependent surf zone; (iv) obtain data on the transport of cobbles in the entire wave-tank surf zone for a broad range of external parameters (size, shape, density and friction coefficient of cobbles, amplitude and frequency of waves and water depth); and, (v) test the analytical/numerical model against the experimental data and to adjust the model as appropriate. The objectives for the permeable slope case are directed to better understanding the detailed physics of the motion fields, including both the water and sand, in the vicinity of model cobbles resting on a sloping beach and subjected to wave motion. In particular, we wish to study: (i) the evolution of the wave-induced velocity field interacting with the cobble; (ii) the interaction of this velocity field with the sand and the associated scouring; and, (iii) the eventual fate of the model cobbles.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

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

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)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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 tank which was designed, developed and tested with the support provided by the present grant. The wave tank is 104.5 ft long, 3 ft wide and 6 ft deep, and 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. Particle-tracking velocimetry (PTV), acoustic-Doppler velocimetry (ADV) and laser-Doppler velocimetry (LDV), as appropriate, will be used to determine the background flow characteristics. An apparatus has been designed and is now under construction that employs two load cells to simultaneously measure both horizontal and vertical forces exerted on the cobble; this facility will be used to obtain measurements of the drag, lift and friction forces noted above. Cobble motions will be monitored by employing video cameras and the resulting data will be analyzed using standard particle-tracking software.

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 and the measurements of the drag, lift and friction forces to refine and extend the models for cobble motions developed under the present grant for the swash (Luccio et al. 1997) and shoaling (Voropayev et al. 1997) zones. In order to better understand and to elucidate complex physical processes that come into play for the study of cobble motions in the presence of a moveable sandy beach, numerical models, based on large-eddy simulation (LES) techniques, will be developed. The initial models will be restricted to the case for which the background flow is oscillatory.

WORK COMPLETED

So far, our research has focused on cobble motions in the presence of impermeable coastal floors; this is a logical first step in this relatively unexplored field of research. The principal outcomes to date are that (i) a theoretical model has been developed to describe the motion of large bottom particles of simple shape (i.e., spheres and disks) in rather arbitrary time-dependent flows such as occur in the shoaling and simplified swash zones and (ii) this model has been found to be in good agreement with measurements taken from physical experiments under a wide range of conditions. The model includes such external parameters as the size, aspect ratio (for disks) and density of the cobbles, the slope and friction along the bottom, and the amplitude and frequency of the waves (for the oscillatory flow case) and the propagation velocity and frontal depth of the bore (in the swash zone model studies). The results are reported in Voropayev et al. (1997), Roney et al. (1997), Roney (1997), Luccio et al. (1997a, 1997b) and Luccio (1997).

RESULTS

Based on the results of experiments conducted in dam-break (swash zone) and standing wave (shoaling region) facilities, theoretical models have been developed to describe the motion of large bottom particles (discs and spheres) in these principally time-dependent flows; see Luccio et al. (1997a,b), Luccio (1997), Voropayev et al. (1997a), Roney at al. (1997) and Roney (1997). In the model swash zone studies a hydraulic bore driven by an impulsive dam-break was used to mimic the background motion. To describe the dependence of the background velocity, u, on time, t, a step function, with the amplitude dependent on the height of water behind the gate, was used in the theoretical model. In the model shoaling region studies, large amplitude standing waves (frequency ω) were established in the test facility and the background velocity $u(t) \propto \sin \omega t$ was used in the model. Typical results of calculations for the motion of a solid spherical cobble in the oscillatory flow are shown in Figure 1. Similar results were obtained in experiments with spherical (solid as well as liquid filled) and discoid-shaped cobbles. In both cases (dam-break and oscillatory flow), reasonable agreement between the measured and calculated values for the cobble motion as a function of time and other parameters was obtained for a broad range of external parameters (cobble diameter, 1.45 - 22 cm, height, 2.3 - 6 cm, density, 1.04 - 7.92 gm cm^{-3}, bottom friction, 0.05 - 0.4 and slope, 0 - 2 ^{o}).

The next natural step toward achieving the goals stated previously, was to modify the model and to apply it to more complicated conditions. In particular, it was important to extend the theoretical model to include situations for which the background velocity depends not only on time but also on the streamwise and vertical coordinates; such complex background flows are typical of those found in the real and simulated surf zones. The model that has been developed is rather general. For the cases in which the background flow is primarily a function of time only, it was possible to derive analytical solutions. For the general case in which the background flow is a function of both time and space it is not possible to derive analytical solutions. For this latter case, the resulting nonlinear, integro-differential (but ordinary) equations for the cobble motion can be solved numerically using standard methods. The main difficulty here is to find the proper parameterizations for the background velocity field in the entire surf zone (see typical example of Figure 2). Then the model can be applied to calculate the cobble displacement and comparison can be made with experiments. Results on this topic are presently being prepared for publication; Voropayev et al. (1997b).

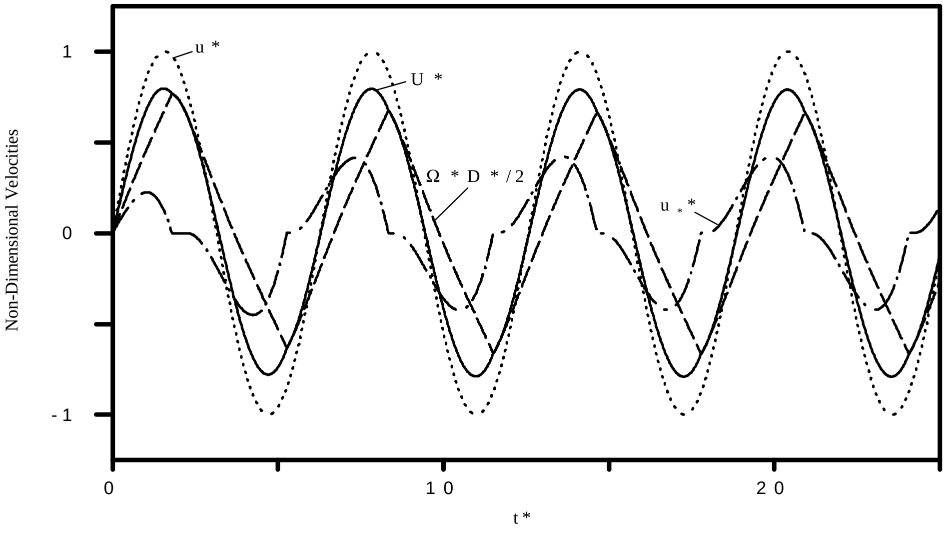

Figure 1. Calculated values for the non-dimensional translational, U*, rotational, Ω*D*/2, and slip, u_*^*, velocities as a function of time, t, for a solid spherical cobble (diameter, 4.42 cm, density, 1.13 gm cm^{-3} and bottom friction, 0.25) in an oscillatory flow (frequency ω, 0.4 Hz and excursion ε, 29 cm). The non-dimensional background velocity, u* ∝ sin ωt, is also shown. From these calculations the phase shift between the cobble and water displacement and the amplitude of the cobble displacement were determined and compared with the measured values in a broad range of external parameters (see Voropayev et al., 1997a, Roney, 1997 and Roney et al., 1997).

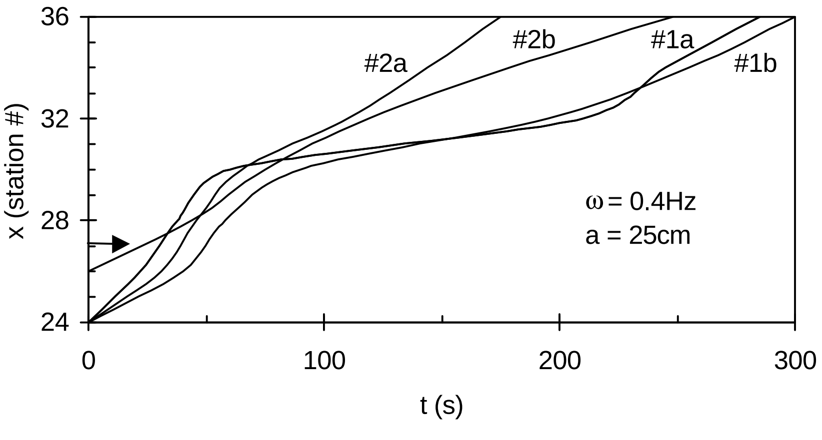

Figure 2. Mean cobble positions (time averaged over 3-4 wave cycles) as function of time; cobble #1 (model mine): (a) fin-shaped bottom, (b) flat bottom; cobble #2 (model cobble): (a) smooth bottom, (b) rough bottom. The point of wave breaking is shown by arrow. The distance between stations in the wave tank with sloping bottom (slope 1:25) is equal to 2 ft.

IMPACT FOR SCIENCE

The motion of "heavy particles", such as cobbles, relative to boundaries such as sloping beaches in the presence of oscillatory and turbulent background motions 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.

RELATIONSHIPS TO OTHER PROGRAMS OR 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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