

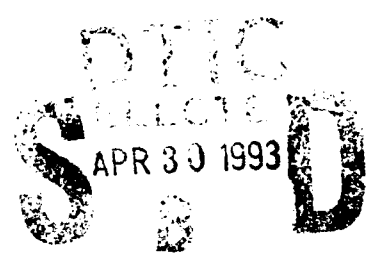


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FINAL REPORT FOR N00014-91-J-1292

COMPUTER SIMULATION OF UNDERWATER SEDIMENT TRANSPORT

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Computer Simulation of Underwater Sediment Transport

Research Goals:

The long-term objective of my research is to understand the physics of the sediment-fluid interaction in the nearshore and its effects on the smallest scale of bedload and suspended load transport, bed microtopography and size sorting; at the level of ripples and other bed roughness elements; and at the scale of larger bedforms and the beach profile.

Objectives:

The objective of the present investigation is to quantify the sedimentological and fluid-flow conditions necessary for the development of nearshore morphology and to determine the origin of the spacing or scale of selected bedform patterns. This study is motivated by the possibility that nearshore morphology is self-organized, meaning that local sediment-sediment or sediment-fluid interactions lead to the observed regular patterns without a global (fluid-flow) pattern imposed on the sand bed. Recently, self-organized models of arid landforms including wind ripples and sorted stone stripes have been proposed. Therefore, a related objective is testing the hypothesis of self-organization against hydrodynamical models for nearshore morphological pattern development. The two patterns of primary focus are rolling-grain ripples and beach cusps.

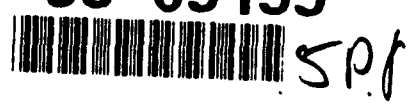
Approach:

Because of rapid advances in computer hardware, it is now possible to utilize computer simulations of sediment-fluid interactions as an experimental tool in which the physical

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assumptions can be specified and in which all information regarding the system is available. To take advantage of these expanding capabilities, computer simulation algorithms for nearshore sediment transport are being developed which will act as a framework for

- testing the importance of various fluid and sediment processes to the formation of particular morphological patterns,
- evaluating the effect of assumptions which underlie sediment transport and morphology models,
- directly measuring the strength of competing models in the development of morphology, and
- generating quantitative predictions of morphology which can be compared to laboratory and field data.

To simulate sediment transport on a range of spatial scales, decreasing detail is incorporated into simulation algorithms with increasing scale. At the smallest scale, bedload transport is simulated using a dynamical model which incorporates explicit treatment of fluid flow near the bed and of grain-grain and grain-fluid interactions. Larger-scale simulations of pattern development transport either grains or packets of sediment according to dynamically derived rules. Stochastic rules for moving grains will be extracted from the dynamical bedload algorithm to model the evolution of a sand surface from a flat bed to ripples. Beach cusp formation is studied by gross treatment of fluid flow and sediment transport in the swash zone over a developing sand surface.

Tasks Completed:

A two-dimensional simulation model for bedload transport has been coded and has undergone preliminary testing. Circular grains interact through dissipative stiff compressional and frictional forces. The fluid is simulated as a "gas" composed of small circular particles ("molecules") which collide both with each other and with the macroscopic grains. Tests of the fluid model indicate good agreement with theory for channel flow and flow past a cylinder.

To evaluate the importance of swash zone fluid flow/morphology feedback to the formation of beach cusps, a model of sediment transport in swash was developed. Cubical or water particles move over the sand bed like a hockey puck on a curved ice surface. The water particles pick up, transport and deposit sediment according to a specified function of velocity. A single swash cycle consists of propelling a row of water particles representing the swash front up the beach and permitting them to move freely up and then down the sand surface under the influence of gravity. Standing subharmonic edge waves are simulated by periodic variation in the initial water particle velocity in the

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longshore direction. Random variations in the initial speed and direction of water particles, swash cycle-to-swash cycle variations in their mean initial speed, and small random changes in the direction of water particle motion throughout the swash cycle are imposed to test the sensitivity to a noisy or variable wave field. Variations in the mean initial direction of the swash front to the beach face normal evaluate the importance of initial wave direction to cusp formation.

Scientific Results:

The swash zone flow model predicts periodic forms which resemble beach cusps, as illustrated in the Figure. The cusp bays begin as cross-shore channels in the beach face which attract seaward-moving water particles, thereby accelerating erosion and resulting in an increase in channel depth and width. The spacing between incipient cusps increases by mergers between cusp bays caused by erosion of the interjacent horn. Horn erosion continues until the curvature of the cusp surface matches the water particle trajectory to keep the water particle speed, and therefore its sediment carrying capacity, constant. The deflection of incident water particles away from cusp horns to cusp bays results in offshore erosion opposite horns and deposition opposite bays, as shown in the Figure.

Simulated cusps form without prior patterns in the fluid flow. Preliminary results indicate that cusp spacing is highly correlated with swash excursion, as predicted by the kinematical model of Dean and Maurmeyer. A subharmonic periodic longshore variation in initial water particle speed results in regular cusps with spacing equal to the half-wavelength. However, in some cases, cusps initially matching the edge wave pattern evolve into cusps with spacing determined by the swash excursion.

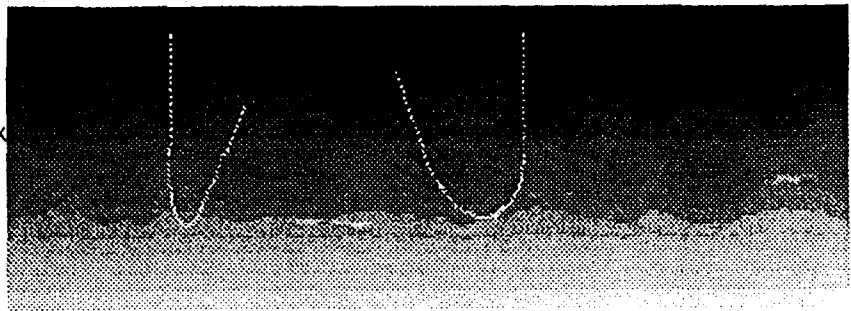
Simulated cusp formation is sensitive to random noise or to other modifications to the Newtonian water particle trajectories. Significant (order 1) variations in swash excursion are found to suppress cusp development because of the necessity for correlation between cusp curvature and swash trajectory. Cusps will not form without a strong coupling between morphology and water particle trajectories. Therefore, a low beach slope or a random response of water flow to sand bed slope prevents cusp development. A swash front moving at a significant angle to the normal (dependent on swash excursion) does not permit construction of the cross-shore channels which evolve into cusp bays. In summary, the simulation model shows that long-crested waves normally incident on a steep beach are the conditions best-suited for cusp formation, in agreement with field observations.

Accomplishments:

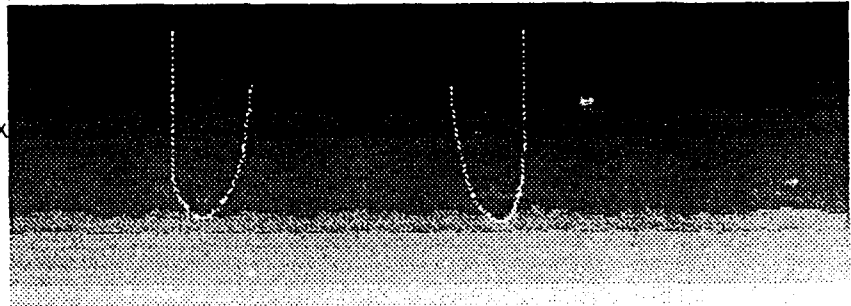
The most significant accomplishment of this research is the demonstration that a regular, self-organized beach cusp pattern can form from local fluid-morphology interactions alone, in the absence of spatially periodic fluid forcing.

ONR-Sponsored Publications

- IC - Werner, B.T., 1991: Fundamentally discrete patterns in geomorphology, Proceedings of the 1991 Woods Hole Oceanographic Institution Summer Study Program on Geophysical Fluid Dynamics, in press.
- C - Werner, B.T. and T.M. Fink, 1991: A model for beach cusps as self-organized patterns, EOS Trans. AGU, 72, 233.
- PI - Werner, B.T. and T.M. Fink: A computer simulation model of beach cusp formation, in preparation.



SWASH CYCLE = 130



SWASH CYCLE = 90



SWASH CYCLE = 50

Simulated beach cusp development from a plane beach through time: after 50, 90 and 130 swash cycles. Black to grey contours denote increasing elevation. Shoreward is down. Sea level is marked by "x." Representative swash particle paths are shown in white. Cusps increase in spacing by merging between cusp bays to match lateral excursion of swash particles. Cuspate morphology is inverted offshore.