Parameterization of a Two-Phase Sheet Flow Model and Application to Nearshore Morphology

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Grant number: N00014-04-1-0217

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Objectives

The overall objective is to develop and test with laboratory and field observations a model that predicts sediment transport and morphological change in the nearshore for a range of wave conditions and sediment characteristics. The specific objectives of this project were to

1. parameterize the wave-induced bottom stress and sediment transport rate using a two-phase sheet flow model,

2. couple the sediment transport model with a time-domain Boussinesq hydrodynamic model to predict beach profile evolution, and

3. improve the two-phase sheet flow model by comparing its predictions with laboratory and field observations of sediment transport.

Work Completed

A small-scale two-phase model [*Hsu et al.* 2004] that concurrently calculates bedload and suspended load transport processes was used to parameterize sediment transport. An earlier study [*Hsu and Hanes* 2004] considered simple wave shapes and suggested that most transport may be in-phase with bottom stress and hence the transport rate can be parameterized by a power law. In the beginning of this project, realistic wave forcing time series measured during the Duck94 [*Gallagher et al.* 1998] and SwashX [*Raubenheimer* 2002] field experiments were utilized to drive the two-phase model and a diluted suspended load model [*Hsu and Liu* 2004]. The validity of the power law approach was confirmed for typical sand grain sizes (d>~0.2mm) and wave periods (T>5sec). The limitation of the power law approach due to the effect of breaking wave turbulence also was studied using field data. The power law must be accompanied with a prediction of bottom stress to obtain the transport rate. Similar to that predicted by a discrete element model [*Drake and Calantoni* 2001], model results tested here with realistic wave forcing also suggest that under strong pitched-forward sea-swell waves, the effect of the boundary layer phase-lag on bottom stress is important. Detailed findings were summarized in a paper [*Hsu and Raubenheimer*, in press] to appear in Continental Shelf Research.

According to these small-scale analyses, several simplified (computationally efficient) approaches that effectively parameterize the effects of the boundary layer and the concentrated region of transport were developed to predict beach profile evolution. When driven by the wave forcing measured during the Duck94 experiment [*Gallagher et al.*, 1998], these simplified approaches were shown to be capable of predicting an observed 5-day onshore sandbar migration event with different degrees of accuracy (see figure 1 for details). Detailed results and findings are summarized in a paper submitted for publication [*Hsu, Elgar, and Guza,* submitted].

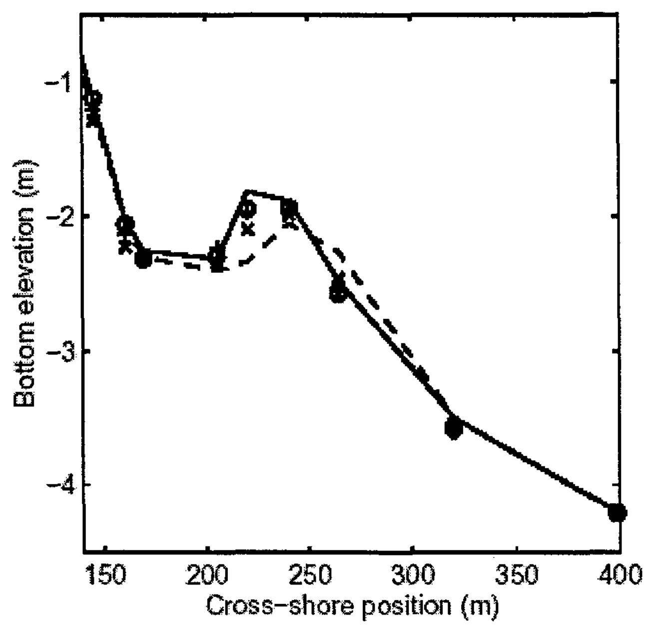

Figure 1: Bottom elevation (i.e., depth relative to mean sea level) versus cross-shore position observed September 22 (dashed curve) and September 27 (solid curve) 1994. Symbols are model predictions of the September 27 profile initialized with the September 22 profile and driven with near-bottom wave-orbital (i.e., demeaned) velocities observed between 1900 September 22 and 2200 September 27. Crosses (x) are the quasi-steady model with a wave friction factor fw =0.01, plusses (+) are the second-order single-phase flow model with a mixing-length closure (roughness, $Ks = 14d$), and circles are the second-order model with k-ε closure ($Ks = 25d$). The quasi-steady model has moderate model skill (0.34), whereas the second-order model with mixing length closure has higher skill (0.57). The highest skill (0.69, circles) is obtained using k-ε closure in the second-order model.

These simplified approaches for sediment transport are further incorporated into a Boussinesq wave model, FUNWAVE. Given the measured offshore wave conditions and initial bathymetry, the Boussinesq model is able to reproduce both the observed surfzone hydrodynamics and beach profile evolution during an onshore sandbar migration event.

Preliminary results were published in a conference proceeding [*Long, Hsu, and Kirby,* 2005]. More detailed results, including erosional conditions are currently in preparation for publication.

Due to the strong undertow current, accurate prediction of beach erosion requires an effective bottom stress parameterization for combined wave-current flow. We developed a standard wave-current boundary layer model (similar to *Mellor* [2002]) that simultaneously resolves the wave and current boundary layers using the Reynolds-Averaged Navier-Stokes (RANS) equation. This type of numerical model captures the nonlinear wave-current interactions and provides accurate bottom stress. However, it is computationally time-consuming to couple these wave-current boundary models directly with wave models for a predictive tool of beach morphology. Under a combined wave-current forcing, the computational requirement for the RANS boundary layer model is significant because the horizontal pressure gradient (energy slope) required to achieve the desired current velocity is not known *a priori* [*Grant and Madsen* 1979] and an iteration procedure is needed. However, given a time history of near-bed flow velocity, it is efficient to calculate only the bottom stress induced by pure oscillatory forcing or pure current forcing (without wave-current interaction). Here, we proposed an efficient phase-resolving bottom stress parameterization for such wave-current interactions. The performance of the new parameterization was tested extensively with random wave forcing (CROSSTEX, Duck94, and SwashX). Detailed numerical model development, validations, and parameterization for wave-current bottom stress are summarized in a paper submitted for publication [*Hsu*, submitted].

Progress also has been made to extend the two-phase model to simulate transport of finer sand. Preliminary comparisons of model simulations with U-tube data measured by *Dohmen-Janssen et al.* [2002] and *O'Donoghue and Wright* [2004] suggest that the refined closure for turbulence-sediment interactions calibrated by the DNS results [*Squires and Eaton*, 1994] is promising. A manuscript summarizing these results is currently in preparation.

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Hsu, T-J, A parameterization of bottom stress and sediment transport in wave-current boundary layer, submitted.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
7 November 2005	Final Report	02/01/2004-09/30/2005

4. TITLE AND SUBTITLE

Parameterization of a Two-Phase Sheet Flow Model and Application to Nearshore Morphology

5a. CONTRACT NUMBERS

5b. GRANT NUMBER

N00014-04-10217

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Steve Elgar and Tian-Jian Hsu (Woods Hole Oceanographic Institution); Daniel M. Hanes (U.S. Geological Survey Pacific Science Center)

5d. PROJECT NUMBER

13021700

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Applied Ocean Physics and Engineering Dept.
Woods Hole Oceanographic Institution
86 Water Street, MS #11
Woods Hole, MA 02543

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING ACRONYM(S)
ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

sediment transport, sandbar migration, nearshore processes, two-phase flow, parameterization

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL	5	Tian-Jian Hsu
					19 b. TELEPHONE NUMBER *(Include are code)*
					(508) 289-2654