Reference Concentration for Shelf Sediment Transport Models

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LONG-TERM GOALS

The scientific focus of this project is to improve our understanding of near-bed suspended sediment concentration (i.e., "reference concentration") in the coastal environment. Models of sediment transport require parameterization of the reference concentration in terms of hydrodynamical and sedimentological measures. We will evaluate the accuracy and suitability of existing expressions for reference concentration, and based on our field investigations, provide an improved expression for this important parameter.

This work is undertaken as part of an ONR-sponsored Mine Burial Research Program. It is closely linked to the work of other investigators who are collaborating to understand the oceanographic and seafloor processes that affect bottom mines. The principal goal of this research is to develop specification of the near- bed reference concentration in terms of other parameters that is tested and supported by high-quality field measurements in the shallow-water marine environment.

OBJECTIVES

- Evaluate existing formulations for reference concentration C_o and their applicability for sediment transport modeling.

- Obtain high-quality field measurements of important parameters that contribute to better understanding of C_o. These include detailed near-bed measurements of wave parameters, velocity profiles, suspended sediment concentrations and size distributions, bed morphology, and particle settling velocities.

- Determine relationships between bottom velocities and stresses in shallow-water marine environments and near-bottom suspended sediment concentrations.

- Develop an accurate expression for C_o.

APPROACH

Our approach is to carry out a carefully designed field experiment to obtain data that can be used to investigate C_o. The study site was seaward of the main pier in Santa Cruz harbor, Monterey Bay, CA, and was selected because of the likelihood for energetic wave conditions, the presence of a well-sorted sandy bed, and relatively simple logistics. Data that were collected included time-series wave measurements, near-bottom velocity profiles, suspended sediment concentrations and sizes close to the

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seabed, bottom sediment sizes, and bed roughness. This research is undertaken in collaboration with Dr. Yogi Agrawal, Sequoia Scientific Inc., and Dr. Peter Thorne, Proudman Oceanographic Laboratory, England. The field experiment occurred over several weeks in March, 2003.

Our results are useful for modeling by other investigators in the Mine Burial Program who are carrying out dynamical sediment transport studies at other locations (shallow water sites on the shelf off west Florida and Martha's Vineyard, MA).

WORK COMPLETED

We conducted a pilot experiment at a coastal site off California (off the main pier at Santa Cruz, CA) in December, 2001. This experiment provided testing of new equipment and sampling techniques. Excellent data on currents and waves were gathered using a Pulse-Coherent Acoustic Doppler Profiler (PC-ADP, SonTek) and single point 3-axis Acoustic Doppler Velocimeter (ADV, SonTek), as well as sonar imagery of the seafloor using a sector-scanning sonar and a narrow-beam high-resolution bathymetric profiler (both instruments from Imagenex Inc.). The sonars resolved small-scale bedforms and small bathymetric changes at repeated intervals. The PC-ADP and sonars were cabled to a recording station on the pier.

The major field experiment was carried out off the main pier at Santa Cruz, CA in March, 2003. A variety of instruments was mounted on two tripod frames and deployed in about 9 m mean water depth off the seaward end of the pier using a crane truck (Figure 1). The tripods were at the same depth, but were separated spatially by about 8 m. Based on diver observations and analysis of surface sediment textures, the surface characteristics at the two tripod sites were similar.

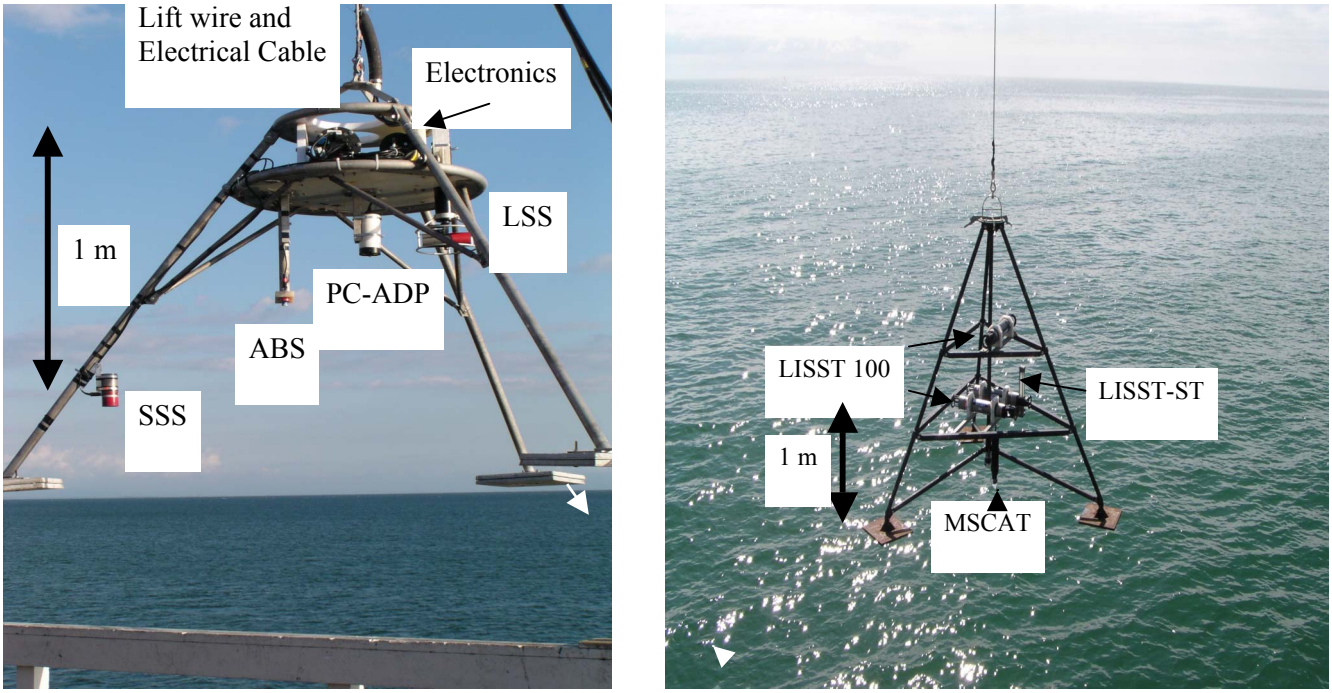

Figure 1. Two tripods being deployed from Santa Cruz, CA pier on March 5, 2003. Left tripod contained hydrodynamic and suspended sediment instrumentation; right tripod was for measurement of suspended sediment sizes and concentrations. SSS - Sector Scan Sonar; LSS - Line Scan Sonar; PC-ADP - Acoustic Doppler Profiling current meter; ABS - Acoustic Backscattering Sensor (P. Thorne). LISST 100 - Laser instrument for particle concentrations and sizes; LISST - ST - Laser instrument for particle fall velocities; MSCAT - Laser instrument for near-bed particle size and concentrations. ABS uses 3 transducers at different high frequencies to determine vertical profiles of particle concentrations and sizes.

RESULTS

Some of the data that were collected with the tripod instrumentation were shown and described in last year's annual report for this project. We were fortunate to capture the effects of a moderate storm that passed through the region on 15-16 March 2003. The storm was a typical late winter event for this area characterized by southerly winds of 20-30 knots that persisted for about 2 days. The measurements indicate that the hourly-averaged currents (non-tidal) reached about 30 cm/s at 1 m above the bed during the storm. Local significant wave heights (Hs) were about 1.5 – 2.0 m; peak spectral wave periods (Tp) were about 12-15 s. Initial estimates of maximum bottom wave velocities (Ub) were about 80 – 100 cm/s. Easily discernible changes to bed morphology were observed in the sonar records. Some of these data and derived parameters are shown in Figure 2.

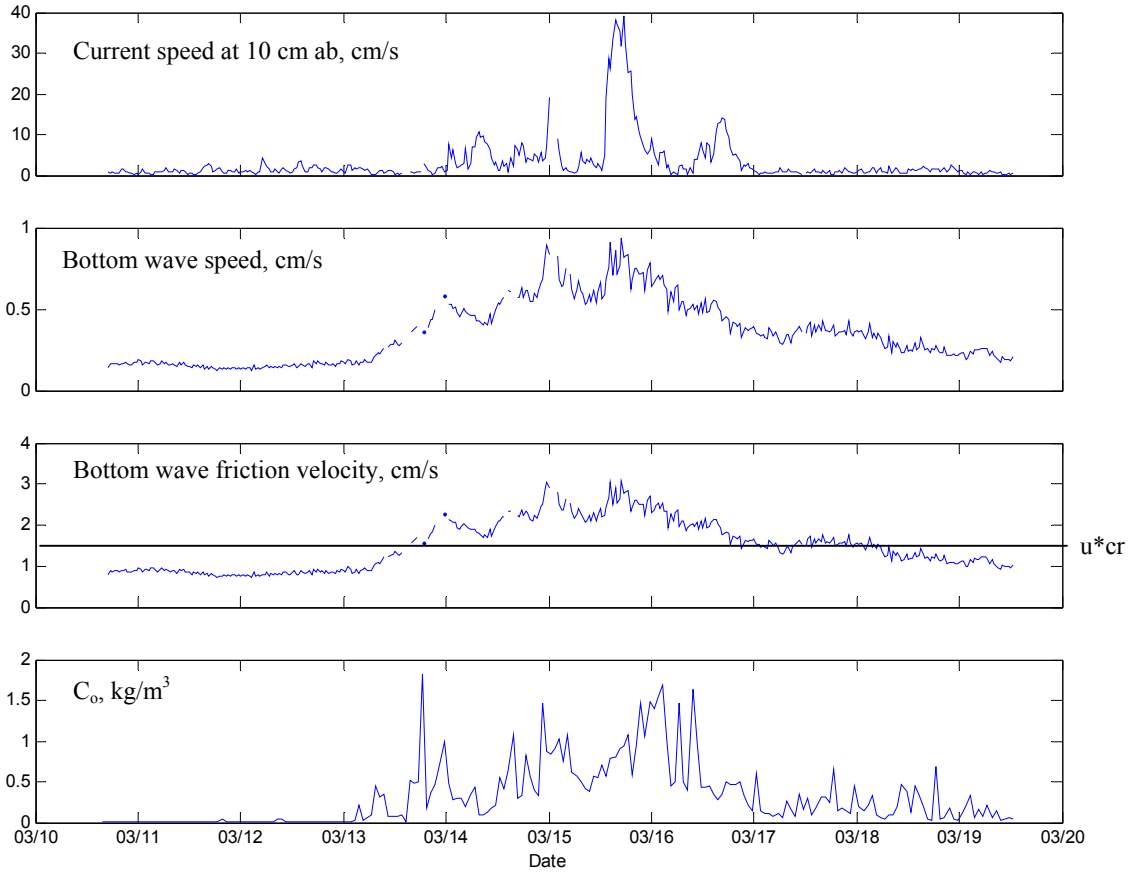

Figure 2. Bottom current and wave speeds measured with the PC-ADP (upper two panels). Wave bed friction velocities (third plot from top) determined from friction factors (Wiberg, et al., 1994). Threshold friction velocity u*cr estimated from Shields curve for sediment with mean diameters of 0.2 mm. C_o estimated from ABS data.

Based on the measurements and analysis to date we have found the following.

(1) Estimates of the empirical proportionality factor γ_o that relates C_o to bed stress are in the range 10^{-3} to 10^{-4} except for low values of excess shear stress ($S < 0.03$). This result agrees with recent choices for γ_o used by Wiberg, et al (1994) and others.

(2) Reference concentrations at 1 cm above the bed (determined from the ABS concentration profiles) were in generally good agreement with the model of C_o that uses the product of Shields and Rouse Numbers (Lee, et al, 2003). Predictions were improved when a correction for ripple roughness was applied to the Shields Number (as proposed earlier by Nielsen, 1986).

(3) The cube of Shields Number (adjusted for ripple roughness) overpredicted C_o (from ABS) at 1 cm above the bed (Nielsen, 1986). Shields Number squared gave better agreement.

Since reporting our preliminary findings, we have continued to analyze the acoustically determined values of C_o, and are hoping to account for effects of suspended sediment grain size variations as determined by MSCAT and LISST. We are also recomputing bed stresses for the measured wave and current speeds using the model of Wiberg, et al (1994). These improved results will be incorporated into our final interpretations and discussion.

IMPACT/APPLICATIONS

The results from our experiments will make important contributions to ongoing modeling efforts in the Mine Burial Program, and to subsequent sediment transport modeling research. We have obtained an excellent data set to investigate the formulation of C_o, and will be able to test models of this important sediment dynamics parameter. Most sediment transport models that have been developed for shallow ocean conditions require specification of the relationships between bottom stresses or shears to concentrations of suspended sediment near the bed. The existing formulations have not been tested and validated under combined wave-current flow conditions above a rough bed. This work will improve this aspect of our understanding and improve modeling of sediment transport.

TRANSITIONS

This work is part of the larger ONR Mine Burial Program efforts. It will be directly integrated into the overall understanding of how bottom mines react to physical processes in shallow water, including scour around mines, mine burial, and mine reorientation and movement. This work will also improve the accuracy of numerical sediment transport models.

RELATED PROJECTS

Collaborative projects are: (1) P.D. Thorne -- Utilization of acoustics for monitoring local and nearfield mine burial processes: Proof-of-concept; ONR Award Number: N00014-01-1-0549; and (2) Y. Agrawal -- Reference Concentration for Shelf Sediment Transport Models; ONR Award Number: N0001499C0448.

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