Numerical Simulations of Sediment Transport and Scour Around Mines

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LONG-TERM GOALS

The long term goal of this research is to understand and predict the scour and transport of submerged objects in coastal waters.

OBJECTIVES

The objective of this research is to verify a computational fluid dynamics (CFD) model for sediment transport and scour of mines in coastal waters with laboratory and field observations. The three-dimensional flow around and scour of partially and unburied mines in the coastal zone is being simulated with a numerical CFD model for both wave and current dominated conditions. The predicted flow, sediment transport and bed scour model is being verified with laboratory and field observations obtained by collaborators (PI Garcia, University of Illinois at Urbana-Champagne (UIUC); PI Richardson, Naval Research Lab; and PI Howd, University of South Florida).

APPROACH

In this research, we are modelling the three-dimensional flow field and sediment transport around submerged objects which have dimensions and characteristics similar to military mines. The FLOW-3D CFD software package is being used to solve for the flow, sediment transport, and evolution of the seabed around the mine under wave and current conditions specified at the boundaries of the numerical domain. FLOW-3D solves the nonlinear Navier-Stokes equations in three-dimensions, and uses the Volume-of-Fluid (VOF) method to track fluid-fluid or fluid-sediment interfaces (Hirt and Nichols, 1981). FLOW-3D also uses the Fractional Area/Volume Obstacle Representation (FAVOR) method to represent the complex boundaries containing the flow (Hirt and Sicilian, 1985). Using FAVOR, the boundaries of the domain (including any obstacles in the flow) can evolve in time and thus can be used to model the changes to the seafloor or to the position and orientation of obstacles, such as mines, within the flow field. FLOW-3D also allows for several turbulence closure schemes to be incorporated and tested. These closure schemes include simple eddy viscosity, one-dimensional Prandtl mixing length, two-equation *k-e*, large-eddy, and four-equation Re-Normalized Group (RNG) models.

The present module in FLOW-3D allows for the movement of sediment as a result of the shear stress exceeding the critical value required for incipient motion (developed to model the erosion of foam duct work in heat transfer problems). The deposition of sediment relies on the two-component drift flux module in FLOW-3D (developed to model snowdrifts in air-snow interaction problems). We will evaluate the applicability of this sediment transport module to wave and mean current flow over non-cohesive sediments which are consistent with intermediate water depths.

The model is initially being evaluated with laboratory observations of flow and scour around a cylinder. As more laboratory (PI Garcia, UIUC) and field (PI Richardson, NRL and PI Howd, USF) observations become available, we will evaluate the model with realistic mine geometries and non-uniform seabed topography with bedforms. Eventually the model results will be used to identify the tendency of a mine to scour or be transported, and provide guidance on the general behavioral characteristics of mines under various flow conditions.

WORK COMPLETED

We (master's student H. Smith and PI) have evaluated the model's ability to simulate flow around a cylindrical object during 5 quasi-steady stages of the scour process. For each of the 5 scour stages, 5 turbulence closure schemes have been compared with the observations. During the PI's collaborative visit with J. Fredsoe and M . Sumer, Danish Technical University, other possible data sets for future model evaluation have been identified.

RESULTS

The model has been used to simulate the two-dimensional flow around a submerged cylinder which is located over 5 different bed profiles. The different profiles represent 5 quasi-steady scour profiles as used in the laboratory experiments of Jensen et al., 1990. The model compares reasonably well with observations in all five of the simulations. In most cases, the model accurately predicts the location of flow reversal and boundary layer thickness upstream and downstream of the cylinder. It shows a boundary layer structure which is significantly modified at more than 10 cylinder diameters downstream. Amplified boundary layer thickness' and decreased bed stresses are present downstream of the cylinder in all 5 of the scour stages.

Figure 1 shows the model-data comparison of the vertical and horizontal velocities for the second stage of the scouring process. At this stage, the bed immediately below the cylinder has been eroded enough to enable flow beneath the cylinder. The model was forced with the measured free stream velocity at the upstream location and k-e turbulence closure model has been assumed. Profile 2 results show the model data comparisons at 10 horizontal locations in the vicinity of the cylinder. The horizontal velocity predictions have R^2 correlations of nearly 1.0 at all locations with a maximum root-mean-square deviation of 5 cm/s at the cylinder. The vertical velocity predictions have significant R^2 correlations (except at 4 diameters downstream) with a maximum root-mean-square deviation of 1.5 cm/s immediately upstream of the cylinder.

Figure 2 shows average model-data comparisons for five turbulence closure schemes for the bed profile representing the 3rd stage of the scour process. In this case, the scour hole beneath the cylinder has tripled in size. In each case, the comparisons represent the horizontal velocity, vertical velocity, and turbulent kinetic energy (when relevant) correlations (R^2), root-mean-square (RMS), and root-mean-square deviations (RMSD) for each horizontal profile averaged over the experimental cross section. In general, these averages for the horizontal and vertical velocities show little variations between models and indicate a simple eddy viscosity model is adequate for predicting the bulk horizontal velocity characteristics. However, the correlations for the turbulent kinetic energy is largest for the k-e model.

These results leave us encouraged that future investigations will continue to provide insight into the dominant physics involved in the object scour process.

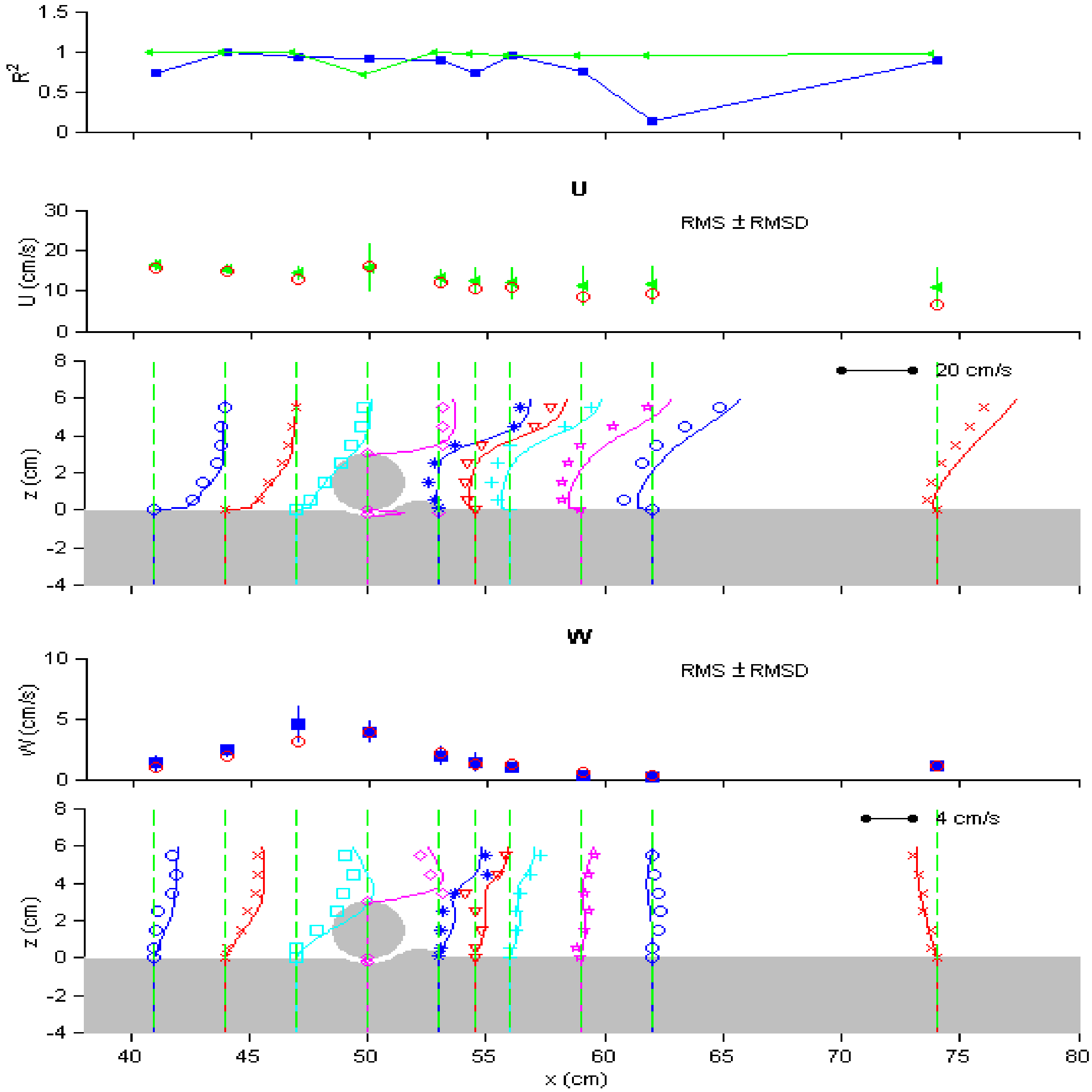

Figure 1. Model-Data comparisons of horizontal and vertical velocities
Upper panel: model-data correlations for both horizontal, U, (triangles) and vertical, W, (squares) velocity. Second and Fourth Panel: Root-mean-squared values (RMS) and root-mean-squared deviations (RMSD) for U (triangles) and W (squares) respectively. The RMS of the laboratory data is represented by the circles. The RMSD values are shown by the error bars. Middle and bottom panel: Velocity profiles at different horizontal locations for U and W respectively. The symbols are the laboratory data and the solid lines are the model output. This figure shows scour profile 2, run with a variable 0.1 cm by 0.1 cm grid and the k-e turbulence model. Laboratory data obtained by B.L. Jensen et. al. (1990).

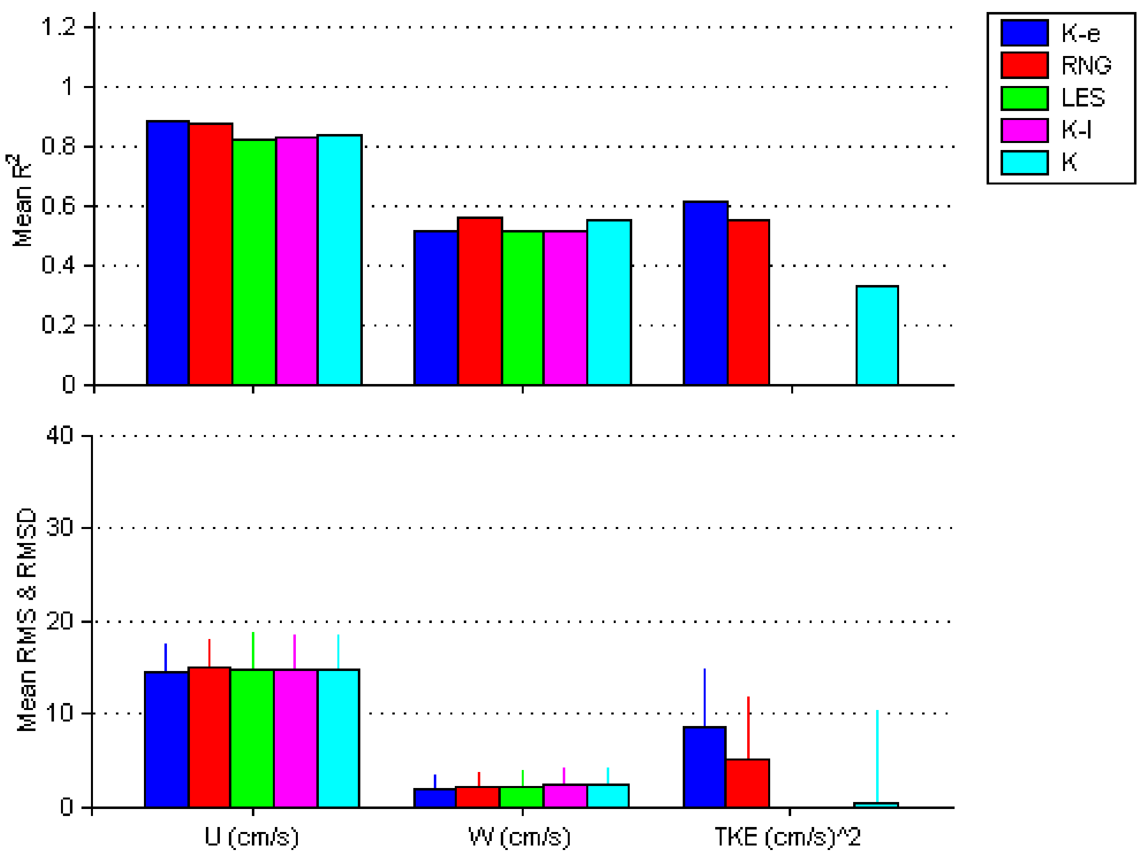

Figure 2. Turbulence Closure Model Evaluation
The comparison of mean correlations (R^2), mean root-mean-squared (RMS) values and the mean root-mean-squared deviations (RMSD) for five turbulence models. The upper panel shows the mean correlations, while the lower panel shows mean RMS and mean RMSD. Each model was run using a variable 0.1 cm by 0.1 cm mesh and rough (0.5 mm) objects. The k-e model has the highest mean correlations and the lowest mean RMSD.

IMPACT/APPLICATIONS

This work is relevant to society and ONR's objectives in two distinct ways. First, current models for predicting the scour of submerged objects rely heavily on empirical models based on existing laboratory observations in idealized conditions and not in natural environments. This investigation will further our understanding of the dominant physics at the fluid-sediment interface. Secondly, these results should improve our ability to predict the scour of mines, bridge piers, and other submerged objects present on the sea floor in the coastal environments

TRANSITIONS

N/A

RELATED PROJECTS

The model developed here will ultimately be compared with laboratory and field observations obtained by collaborators (PI Garcia, University of Illinois at Urbana-Champagne (UIUC); PI Richardson, Naval Research Lab; and PI Howd, University of South Florida). This project will also benefit from current and future scientific exchanges with the Danish Technical University (PI's Fredsoe and Sumer).

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PUBLICATIONS

Smith, H. D. and D. L. Foster (2001). "Modelling of Flow around a Cylinder over a Scoured Bed." In prep. C*oastal Engineering.* In prep.