Wave-Current-Induced Mine Burial Due to Sediment Fluidization and Scour

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LONG-TERM GOAL

The long term goal is to improve the U.S. Navy's capabilities for Mine Burial Prediction (MBP). A recent workshop on MBP recommended the use of large-scale laboratory experiments, that can be coupled with field observations, statistical analyses and mathematical modeling, with the goal of enhancing the mine burial predictive capabilities of the U.S. Navy (Bennett, 2000). This work was motivated by such recommendation as well as the belief that well conducted laboratory observations will provide a vital bridge between field measurements and numerical modeling of mine burial processes in shallow waters.

OBJECTIVES

The main objective of this effort is the development of a mechanistic model for Mine-Fluid-Sediment (MFS) interaction that accounts for uncertainties about the loading functions (currents and waves) and the sediment properties (particle size, porosity, density, etc). Once the MFS interaction model is developed and tested, it will be used to generate a set of probability density functions for mine burial as a function of intensity of environmental forces, mine characteristics, water depth, sediment properties, and geo-technical parameters (e.g. Lopez and Garcia, 2001).

APPROACH

Our approach is to conduct laboratory experiments with two special-purpose facilities that will help towards the development of a MFS interaction model by the ONR Mine Burial Prediction Team. One facility is the Large Oscillating Water Sediment Tunnel (LOWST) which is currently being constructed with DURIP support. The second facility is an existing multipurpose flume.

The main objective of these experiments will be to study the mechanical stability of the mine-sediment system under the hydrodynamic loading produced by different combinations of currents and waves in shallow water conditions. The multipurpose channel is 4 feet (1.20 m) deep, 6 feet (1.8 m) wide, and 161 feet (49.2 m) long. The channel is equipped with a sediment feed and removal system. When used for wave studies, a piston type wave generator is placed in the channel about 135 feet from the downstream end. A pumped circulatory system to provide the water current component is being added. In this fashion, it will be possible to superimpose a current on the wave motion generated by the piston.

The experiments in the wave-current flume will concentrate on the following aspects:

<u>Fluid forces on model mines and sediments</u>: the effects of flow separation in currents and waves and evaluation of patterns of broad-band, wave-induced vortices about typical mine shapes. Threshold of motion criteria for sediment due to mine-induced vortices in a boundary layer flow, will be researched as well. Hydrodynamic loading on mines will also be characterized taking advantage of the large size model mines.

<u>Stability of mine-sediment system</u>: we will investigate the mechanism of sandy sediment scour and failure under cyclic loading and re-suspension and dispersion in wave-current boundary layers and study the effects of sediment non-homogeneity (grain-size distribution, and density stratification). Different sediment beds will be used ranging from sandy beds to muddy bottoms (Admiraal and Garcia, 2000a). Particular attention will be paid to the potential for mine burial due to fluidization of mud by waves (Foda et al., 1993).

Both the hydrodynamic forcing on exposed model mines as well as the pore-pressure distribution on the buried portion of the mine and surrounding sediments, will be measured. In these experiments, we plan to help with the testing of field sensors (R. Bennett, personal communication). Acoustic sensors will be used to measure both flow velocities and suspended sediment concentration profiles (Admiraal and Garcia, 2000b). In particular, we will concentrate on the response of the mine-sediment system to the applied wave-current forcing and the resulting mine burial (Mei and Foda, 1981; Foda et al., 1990).

WORK COMPLETED

The wave generation system was upgraded. A new hydraulic pump and a more sophisticated controller were purchased and installed in order to generate a wide range of wave conditions.

A water re-circulation system was also added to the wave tank. A movable bed made of medium sand was placed inside the flume. Preliminary experiments were conducted with monochromatic waves. Software need to produce waves was developed.

A movable-bed was installed in the wave-current tank together with a an artificial beach to reduce wave reflection from the end of the tank. Conductance-type wave gages were tested and calibrated.

Particle-image-velocimetry (PIV) was used to study the flow field around a model mine under oscillatory flow conditions. It became clear that a new more powerful laser was needed. However, the methodology to conduct PIV measurements is now working well and will be tested in the wave tank as soon as the new laser is in place.

RESULTS

The main result has been the successful performance of particle-image-velocimetry (PIV) measurements around a model mine under oscillatory flow conditions (see Figure 1). Observations clearly show an area of recirculation in front of the model mine, where there is great potential for scour. Also of relevance has been the upgrading and calibration of the wave-current generation system. Preliminary experiments clearly show scour around model mines (concrete cylinders) for mean current velocities of about 30 cm/s. Ripples seem to develop naturally along the movable bed even for incipient sediment motion conditions.

RELATED PROJECTS

Within the Mine Burial Prediction Program there are a number of related projects. In particular, substantial cooperation is expected with Prof. C.C. Mei, MIT, Prof. Harindra Fernando, Arizona State University, Prof. Horst Brandes, University of Hawaii, Dr. Richard Bennett, SEAPROBE, and Prof. Patricia Wiberg, University of Virginia.

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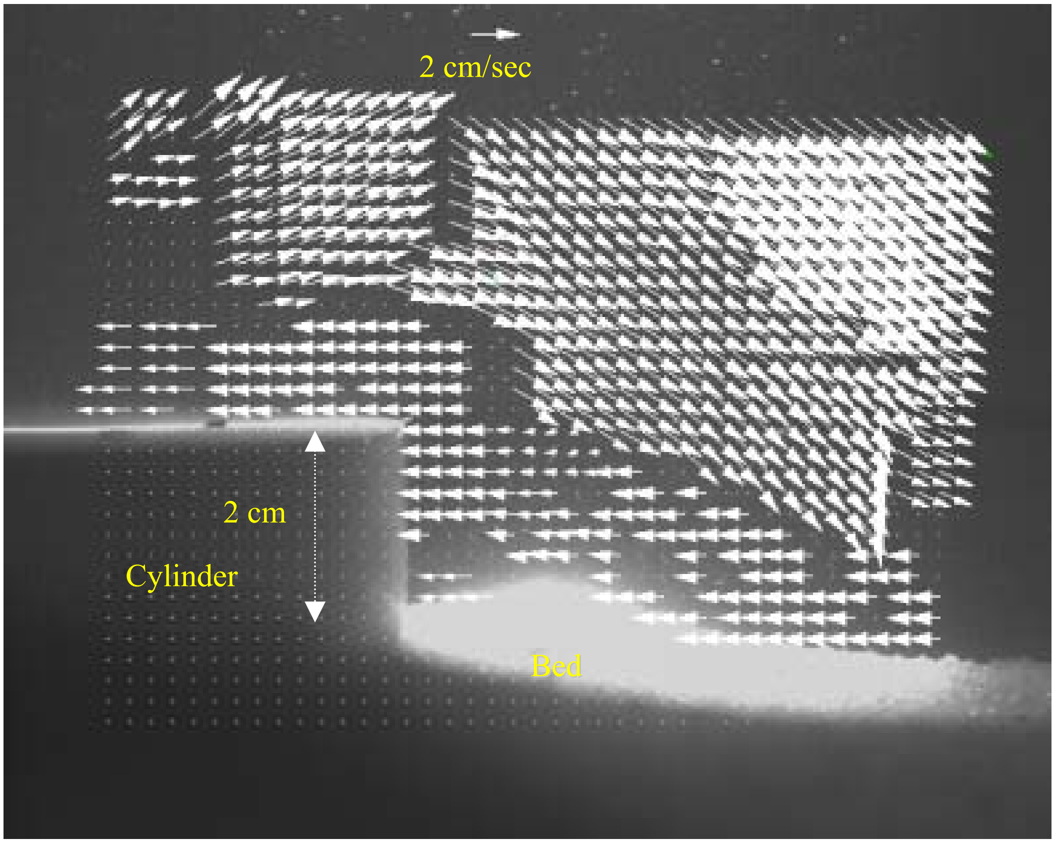

Figure 1. Flow velocity field around a model mine (cylinder) obtained with particle-image-velocimetry (PIV). Notice the zone of re-circulation in front of the cylinder, where bed sediment scour can be expected to occur.