Mine Burial Prediction: A Cooperative NRL/ONR Study

M. D. Richardson, P. J. Valent, T. K. Holland, K.B. Briggs and C.L. Vincent
Marine Geosciences Division
Naval Research Laboratory
Stennis Space Center, MS 39529-5004
phone: (228) 688-4621 fax: (228) 688-5752; e-mail: mike.richardson@nrlssc.navy.mil

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LONG-TERM GOAL

Development of an accurate, real-time mine burial prediction capability by field testing and validation of an integrated, physics-based mine burial model.

SCIENTIFIC OBJECTIVES

Seabed-structure interactions are responsible for the burial of heavy objects, such as mines, pipelines, concrete breakwaters, platforms, debris, and other objects on the seafloor. In low shear strength muds, these objects are known to bury at impact or to sink into the sediment if the buoyant weight of the object exceeds the bearing capacity of the seafloor. In higher energy sandy sediments, burial by scour and fill, momentary or cyclic wave-induced liquefaction, and seabed morphological changes (e.g., transverse bedform migration, changes in shore-rise and bar-berm conditions, sediment deposition) is common. Using a field experimental approach, NRL will test and evaluate physics-based mine burial processes and models in order to provide the US Navy with an accurate, real-time mine burial prediction capability.

APPROACH

The Naval Research Laboratory (NRL) is responsible for development, deployment, and analyses of data from instrumented mines; impact burial experiments; development of an improved impact burial model; assessment of the effects of uncertainties in the input parameters for prediction of a mine burial models; and the development of an integrated mine burial model.

One of the major problems in the experimental validation of mine burial models is the difficulty of continuous measurement of the behavior of the mine. Second-generation instrumented experimental mines, developed by NRL, provided the first tool for continuous monitoring of the movement of the mine (heading, pitch and roll) as well as the percentage of the surface area of the mine actually buried during several mine burial experiments (see Richardson et al., 2001; Griffin et al., 2001; Valent et al., 2001). The next generation instrumented mines (scheduled for completion in the summer of 2002), were developed by OMNI Technologies Inc. under the direction of NRL as part of a Small Business Innovative Research (SBIR) initiative and will extend that capability to characterize developing scour pits, migrating sand dunes or ripples; quantify the boundary layer flow around the mine; measure sediment concentrations and flux in the vicinity of the mine; measure sea state and bottom currents; determine initiation of bed load transport; and calculate sediment transport. Additional instrumented mines are being purchased by ONR and NRL. A second mine type (scheduled for completion in fall,

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2001) is being developed for impact burial experiments that is capable of monitoring mine motion across the air-water interface, through the water column (x,y,z accelerations and roll pitch and yaw), and penetration of the mine into the sediment, including measurement of percent mine burial.

NRL leads the effort to improve the Impact Burial Prediction Model (IMPM) using data collected in tank and field tests during FY01-02. NRL is responsible for improving and validating the sediment penetration module and for integrating a hydrodynamic module and stochastic relevance into a final impact burial model. Field experiments on burial by scour and fill; bedform migration; bedform morphological alterations; liquefaction or fluidization of the sediment; and biological processes are scheduled for the winters of 2002-3 off Tampa Bay and 2003-4 at the Martha's Vineyard Coastal Observatory. For all these experiments, NRL is responsible for a) deployment, and analyses of data from instrumented mines, b) quantification of environmental processes in the mine near field and c) 3-D visualization of mine movement. These data will allow development and validation of new and proposed mine burial models.

Advances in our physical understanding of mine burial and new mine burial models, including NRL modifications to the impact burial model, which result from these joint experiments, will be integrated into a framework for a stochastic approach to mine burial prediction (Fig 1). This model recognizes that mine or object burial is time dependent, spatially and temporally variable and that burial processes are not independent (Richardson et al., 2001). The integrated mine burial model will allow time-dependent mine burial prediction from numerical oceanographic models or in situ measurements of wave climate and tidal and storm-induced bottom currents, sediment physical properties and small-scale morphological features measured in situ or compiled in historical databases, and characteristics of the mine threat based on intelligence. The model (preliminary version in 2002) provides both strategic and tactical mine burial prediction.

NRL will also assess the effects of uncertainties in the input parameters for predictions of a mine burial at impact and by subsequent burial through a stochastic simulations involving most free parameters. This differs from a sensitivity analysis where typically the effect of one variable is found through its variation. Here all variables can vary and the model's convolution of the uncertainty through its nonlinearity can be addressed.

WORK COMPLETED

A field experiment off the mouth of the Mississippi River Mouth was conducted during November 2000 and hydrodynamic experiments were conducted at NSWC test pond at Carderock, Maryland during 10-14 September 2001. Both experiments were directed towards understanding mine burial at impact. In the Mississippi Delta field tests, 16 test drops in 12 m water depth were run with the NRL instrumented mine model, a blunt cylinder 18 cm diameter by 60 cm long. The 500 kg model was released when just below the water surface from horizontal and nose 45- and 90-deg down orientations. We established that this typical shape rotated to about a 20-deg nose down orientation within a fall of two mine lengths and approached a vertical speed of 3 m/s. The IBPM was shown to be deficient in that it did not predict the observed rotation to 20-deg nose-down orientation and thereby overpredicted mudline impact velocities and impact burial depths. This finding was reported in a poster and paper at the Second Australian-American Joint Conference on the Technologies of Mine Countermeasures held in Sydney Australia during 26-29 March 2001.

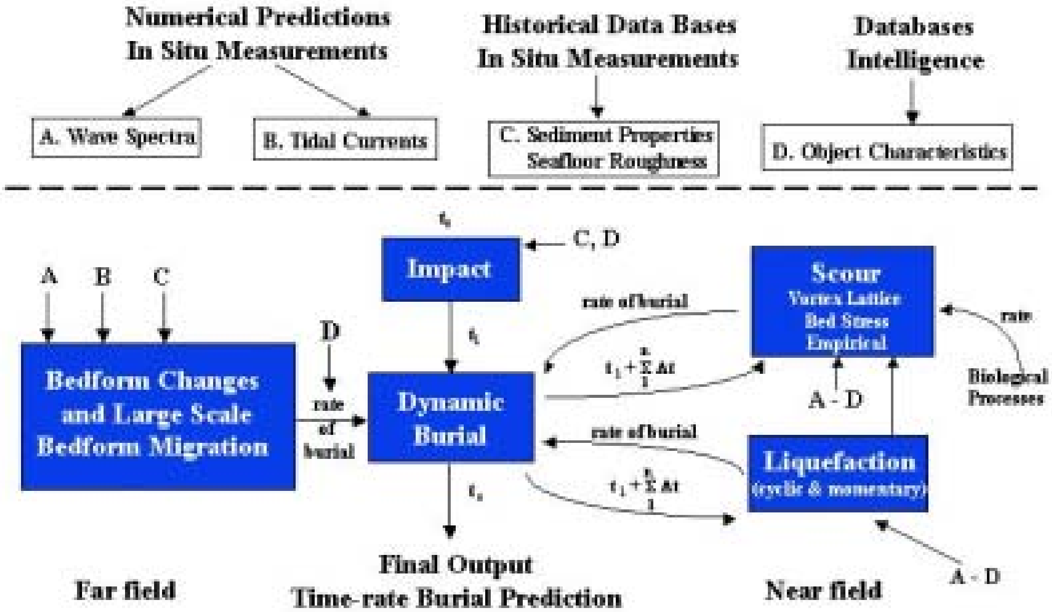

Figure 1. Flowchart for an integrated mine burial model

The inadequacy of the IBPM to predict mine fall in the water column prompted a closer look at the hydrodynamics of cylindrical mines falling in the water column. In the NSWC-Carderock Test Pond tests, 203 drops total of six 1/3rd-scale mine models were conducted in 8 m water depth. The models were of differing bulk unit density, length-to-diameter ratio, center of mass location, and nose shape, generically representing known threat, anti-ship, bottom mines. The models were released from various orientations to free-fall from above and below the water surface. Digital video data were obtained from multiple cameras above and below the water surface. The digital imagery is now being reduced to model displacements, velocities and orientations for in-house analyses and distribution to ONR Mine Burial Program participants at MIT, NPS and TAMU. Very preliminary review of the video data suggests the fall of the models can best be described as "chaotic".

Data collected during previous mine burial experiments was analyzed and reported at Second Australian-American Joint Conference on Technologies of Mine Countermeasures held at Sydney Australia, 27-29 March 2001. The experiments included scour and shoreface morphological changes at Scripps Pier in August – September 1999, sand dune migration in Destin Inlet during October – November 1999; scour and liquefaction of the US Army Corps of Engineers Pier at Duck NC in May 2000, and impact burial experiments in Mississippi Sound during September 2000. Techniques used for 3-D visualization of mine movement were developed and tested based on data collected during the Scripps Pier and Destin Inlet experiments.

A full-size instrumented mine has been designed for impact burial experiments. Instrumentation in this mine consists of a 3-axis fiber optic gyro (FOG) 3-axis accelerometer, and 3-axis magnetometer. NRL has developed an algorithm capable of processing data from these instruments into a 3-D visualization of the mines trajectory and orientation during deployment. The system has been tested under controlled laboratory conditions and is capable of measuring position and orientation with less than 2.5% error over typical deployment scenarios. Field-testing of this mine is scheduled for November 2001 and impact burial experiments are scheduled in shallow waters off Corpus Christi, Texas in March 2002.

RESULTS

Field experiments conducted by NRL have documented that the Impact Burial Performance Models (IBPM) inadequately describes the physics of object fall through the water column, thus throwing into question the mine velocities calculated for the water column, and the kinetic energy used to by IBPM to calculate penetration below the mudline. NRL therefore conducted a series of hydrodynamic experiments at NSWC Carderock Maryland during 10-14 September 2001. The experimental mines used during these experiments were 1/3 scale compared to the types of mines that are likely threats to U.S. and allied forces. The length/diameter ratio, distribution of mass relative to the center of volume, and the nose treatment were varied during these drop experiments. Mine movement across the air-water interface and through the water column was characterized using video photographic techniques. Very preliminary review of the video data suggests the fall of the models can best be described as "chaotic".

Instrumented mines were able to characterize mine movement and burial due biological processes, shoreward bedform migration, shifts in shoaling wave direction, migrating sand dunes resulting form tidal currents, and wave-induced scour. In general, biological scour results in negligible mine burial. Based on measured sand dune size (length and height) and migration rates for experiments conducted in a tidal inlet, the average time for initial burial of randomly placed mines is 50 days. The percentage of fully buried mines after 100 days ranges between 30-70% depending on the value of the dune height used. The range of predicted size and of predicted migration rates of sand dunes in this inlet varied by a factor of 4 depending on the which bedload transport model is used. Predictions of near-field mine by sediment transport by vortices shed from the mine shape (scour) and far-field burial by changes in beach profiles due to accretion and erosion were reasonably accurate. The potential for mine burial by wave-induced liquefaction was uniquely demonstrated by comparison of time series fluctuations in bottom pressure (from passing surface gravity waves) and fluctuations in shear wave speed (a proxy from sediment strength) in surficial sediments. Three dimensional visualization techniques provided unique insights into characterization and understanding mine burial processes. Comparison to predictions from mine burial model suggests considerable work need to be done.

IMPACT/APPLICATIONS

Buried mine detection has been and is still one of the greatest threats facing shallow water Mine CounterMeasures (MCM) operations. The possible presence of buried mines can change MCM tactics from one of mine hunting to one of minesweeping or area avoidance. The ability to predict mine burial both for planning and during operations (strategic and tactical scenarios) is therefore of great importance to Naval forces.

TRANSITIONS

At the completion of the joint ONR/NRL experiments a fully operational integrated, physics-based mine burial model will be transitioned to NAVOCEANO. In the interim, fully operational instrumented mines (impact and subsequent burial mines) will be completed and used as part of the ONR mine burial experimental program. Impact mines will allow characterization of the 6-degrees of motion (x,y,z accelerations and roll pitch and yaw) thus monitoring mine motion across the air-water interface, through the water column motion, and penetration of various cylindrical mine configurations (mass, weight distribution, nose types) into the sediment. Instrumented mines designed for subsequent burial will allow characterization mine movement (heading, pitch and roll), percentage of the surface area of the mine buried, as well as provide the capability to characterize developing scour pits, migrating sand dunes or ripples; quantify the boundary layer flow around the mine; measure sediment concentrations and flux in the vicinity of the mine; measure sea state and bottom currents; determine initiation of bed load transport; and calculate sediment transport. A new impact mine burial model with corrections to the hydrodynamic module will be transitioned to NAVOCEANO.

RELATED PROJECTS

The work unit is part of ONR's Mine Burial Processes (MBP) program. The MBP processes program includes at least 35 separate projects. The Naval Research Laboratory also supports its investigators with significant internal 6.2 funding (Mine Burial Processes)

REFERENCES

See below

PUBLICATIONS

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PATENTS

None