Sand and Mine Response Modeling

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LONG TERM GOALS

The goal of the sand modeling effort is to provide a validated predictive capability for the propagation of shock waves through the surf zone (SZ) environment of water, sand, and entrained air. Since the details of the physics are included in the model, this tool is also capable of modeling the response of the threat mine structure to the shock wave. Previous SZ explosive mine countermeasures (MCM) systems experimental data have indicated that explosive shock waves were highly attenuated when propagating through the sand bottom. The rate of attenuation was determined to be sensitive to the saturation level and skeletal characteristics of the sand bottom. Because of environmental limitations, all explosive testing in the United States for the SZ MCM project has been conducted in artificial test ponds. It has been recognized that the bottom conditions in man made test ponds do not necessarily represent natural beaches; therefore it is essential to have a methodology to relate test pond results to real world beaches.

OBJECTIVES

The objectives of the FY98 effort are to:

1. Update and debug the P-α and effective stress sand material models in the DYSMAS Eulerian-Lagrangian-coupled (ELC) hydrocode.
2. Validate the sand models by simulating laboratory and field experiments.
3. Complete the validation database for experiments conducted under the sand and mine response modeling task.
4. Examine the effects of multiple shocks on sand bottom response through experiments.

TECHNICAL APPROACH

Both the P-α sand model and the effective stress model (ESM) have been implemented in CTH and DYSMAS hydrocodes. The main focus in FY98 was to validate the sand models using the experimental results from spherical shock wave propagation experiments, the sand and mine structure interaction (SAMSI) tests, and the sand cylinder tests. These simulations emphasize the ability of the sand models to handle shock wave propagation in the sand medium as well as the sand/fluid-structure interaction. Results from these validation calculations will also be used to assess the necessity to implement the MCF model into the DYSMAS hydrocode in FY99.

The sand medium from the Eglin Test Pond and Beach (Florida), Waterways Experiment Station (WES) Test Pond (Mississippi), North Hampton Beach, New Hampshire, and Port Wakefield Beach,

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Australia were characterized. These test data can be used to validate the sand models in the hydrocodes. In addition, the data can be used to relate the test pond test results to real world beach test results. Hence, participation in fleet exercises or other tests involving real beaches is essential for the success of the sand-modeling task. A series of joint tests was conducted under The Technical Cooperation Program (TTCP) at Weston-Super-Mare. The purpose, for Britain, was to study obstacle clearance using the British Giant Viper line charge in FY96. Since the sand and Giant Viper explosives (PE6-AL) had not been characterized, this data could not be used for model validation. In order to use this data, the sand and the explosives must be characterized. The dry and wet sand from Weston-Super-Mare can be characterized using compression tests similar to those used to characterize the sand from Port Wakefield. The PE6-AL explosives can be characterized with cylinder expansion (CYLEX) tests. Since the explosive MCM systems currently under development use distributed explosive technology (SABRE and DET), the effect of multiple shocks in the sand-air-water mixture needs to be investigated. The shock wave from the first charge may compact the mixture and raise the shock propagation speed and the intensity for the subsequent shock waves. The ability of the sand models to predict this phenomenon needs to be examined. Experiments using sequentially detonated detcords were performed to investigate this problem. Results from the experiments give a general indication of the importance of the multiple shocks for MCM related problems.

WORK COMPLETED

Sand Model Update and Debug. The latest master release of the DYSMAS hydrocode (March 1998 version) contains both the P-α model and the ESM. The numerical method (pressure iteration scheme) used in the DYSMAS hydrocode was improved (made more robust and more efficient) in FY98 to provide a better coupling with the P-α and the ESM. The P-α model is fully functional, and was used for simulating the validation experiments. However, the ESM still has numerical instabilities even with the improved pressure iteration scheme.

Sand Model Validation Simulation. Currently, there are four complete sets of experimental data (free field data, target response data, and sand characterization data) available for sand model validation: (1) the spherical shock propagation in saturated sand experiments conducted by SRI International; (2) the SAMSI tests conducted at Waterways Experiment Station; (3) the SAMSI tests conducted at Port Wakefield, Australia; and (4) the sand cylinder tests conducted at Lawrence Livermore National Laboratory. In order to perform the validation simulation, the appropriate sand model coefficients were needed. In the past, trial and error was used to adjust the coefficients until the simulation results matched the experimental data. In FY98, a methodology was developed to generate the P-α model coefficients based on the sand characterization tests, specifically, the hydrostatic compression test data. Validation simulations were performed using the newly generated P-α sand model coefficients against the SRI International spherical shock propagation tests, the WES SAMSI tests, and the sand cylinder tests. Sensitivity studies were also performed based on the spherical shock propagation tests and the WES SAMSI tests to study the effect of air content on the explosive shock wave.

Sand Model Validation Database. To expand the database, the dry and wet sand from Weston-Super-Mare was characterized using hydrostatic, uniaxial, and triaxial compression tests. A draft report on the Weston-Super-Mare sand characterization tests was completed. Since the PE6-AL explosives contained a large percent of aluminum (about 17%), both 1-inch and 4-inch cylinder expansion (CYLEX) tests are required to characterize the explosive. The 1-inch CYLEX test of PE6-AL has been completed. The cost of these characterization tests was shared with the United Kingdom under TTCP.

Multiple Shock Experiments. A series of tests was conducted at Port Wakefield, Australia under TTCP to study the response of the sand using time delay detonated SX-2 explosive detcords. These tests will provide a general indication of the importance of the multiple shocks for MCM related problems. The documentation of the test series and data analysis will be completed in FY99.

RESULTS

The eight parameters describing the P-α model are detailed in reference 1. Determining P-α sand model coefficients is ideally a two step procedure. The first step is to determine the Mie-Gruneisen coefficients for the "solid" saturated sand mixture. The second step is to determine the coefficients, which describe the pore-air behavior. For each step, the necessary data is the pressure as a function of density from high stress (400 MPa or higher) hydrostatic compression tests. The hydrostatic compression tests were assumed to have an isentropic thermodynamic path (a quickly loaded specimen, free from any heat transfer). Using this procedure, the P-α sand model coefficients were generated for the Eglin Air Force Base (AFB) test pond sand, the WES test pond grout, and the Port Wakefield natural beach sand. The coefficients are provided in Table 1.

Parameter	**Eglin AFB Test Pond**	**WES Test Pond (Grout)**	**Port Wakefield Beach**
$\mathbf{p_{ref}}$	0 dynes/cm^2	0 dynes/cm^2	0 dynes/cm^2
ρ_{ref}	2.0642 g/cc	1.446 g/cc	1.8934 g/cc
$\mathbf{e}_{ref}$	0	0	0
Γ_o	0.963	0.963	0.963
S	5.0	3.6	3.2
C_s	1.870E5 cm/s	1.330E5 cm/s	1.478E5 cm/s
α_0	1.042	1.017	1.0018
P_s	1.0E8 dynes/cm^2	1.25E7 dynes/cm^2	8.99E6 dynes/cm^2

Table 1. P-α Coefficients for Various Sand

The validation simulations using the P-α model in combination with the DYSMAS hydrocode were performed and compared with the spherical shock wave propagation in sand experiments conducted by SRI International.[2]. Since these experiments used the Eglin AFB test pond sand, the corresponding sand coefficients from Table 1 were used in the DYSMAS hydrocode calculations. An examination of the analysis results indicated that the level of the computed velocities and pressures are consistent with experiment. In addition, the simulation results using the new P-α coefficients are similar to those from the FY97 simulation results using a trial and error method to determine the P-α coefficients. Another purpose of the spherical shock propagation experiments was to determine the sensitivity of explosive shock strength as a function of air content. DYSMAS simulations were performed to examine this question. Figure 1 shows the impulse as a function of air content. Note that the impulse decreases rapidly (by more than 30%) as air content increases from 0% to 2%. This also shows how important it is, when conducting experiments with wet sand, to control the wet sand medium in order to provide validation quality data. The WES SAMSI test validation simulations were performed in FY98. The purpose of these simulations was to assess the capability of the sand model to apply the proper loads to a mine-like structure. The WES SAMSI tests are detailed in Reference [3]. The coefficients in Table 1 were used in the DYSMAS coupled calculations of the SAMSI tests. Figure 2 shows the DYSMAS simulation result for SAMSI shot 5 and 6 versus the test results. The test configuration for shot 5 and shot 6 is the same (8 pounds pentolite on the sand-water interface) except the mine standoff for shot 5 and shot 6 are 46 inches and 44 inches, respectively. The calculated mine deformation is 15% low compared to shot 5 and 25% high compared to shot 6. The difference can be attributed to the non-uniform and highly stratified test pond sand bottom as detailed in Reference [3]. The in-situ air content measured in the sand bottom column varied from 0.9% to 2.5%, and the calculations were performed with a weighted average of 1.7% air content. Based on the air content sensitivity study, the variation observed can change the impulse by more than 15%. Nevertheless, the comparisons showed that the P-α sand model did a creditable job of simulating the sand bottom, and the modeling capability is within the experimental error. The sand cylinder experiments were designed to produce high quality validation data for the sand models. The experiments were conducted under the U.S./Germany DYSMAS Project Agreement. These experiments are very similar to the SRI International experiments for study shock wave propagation in sand. The schematic for the experiment and a comparison of the DYSMAS calculation result and the test result are provided in Figure 3. The calculation showed excellent agreement (less than 5%) with the test data.

These validation simulation results indicated that the P-α model is capable of modeling a well-characterized wet sand medium. The P-α model in combination with the DYSMAS hydrocode can adequately predict the propagation of shock waves through the SZ environment of water, sand, and entrained air, and the response a structure to the shock wave. However, the P-α model can still use improvements such as the inclusion of a deviatoric component to model the shear load in the sand (to mimic the ESM). In general, the structural response predicted by DYSMAS is low compared to test data; the shear load may solve this problem.

IMPACT AND APPLICATIONS

The ultimate payoff of the sand modeling task will be providing the hydrocode capability to simulate the whole mine neutralization process from the explosive detonation to shock wave propagation through sediment to mine response (destruction). Since it is almost impossible to sample and characterize a hostile beach, the experimental database and the sand models provide the only means to predict the performance of the MCM systems.

TRANSITIONS

As this work progresses, experimental data and validated sand models are continually transitioned to 6.2, 6.3, and 6.4 SZMCM programs. This task provided the sand models to the distributed explosive performance task to conduct the parametric hydrocode analyses which form the data base of the distributed explosive performance analytic code (DEPAC). When the sand models are validated with the DYSMAS coupled hydrocode, it will provide the mine vulnerability task the ability to develop kill criteria for threat mines.

RELATED PROJECTS

In collaboration with The Technical Cooperation Program (TTCP), the Bottom Interaction Program at the Naval Research Laboratory, the Stennis Space Center, and the Buried Explosives Against Shallow Targets test program of the Defense Special Weapons Agency, well controlled and characterized test pond and real world beach tests were performed to provide validation data for the sand models. In addition, experiments to determine the need for a three-phase sand model are being conducted under the U.S./Germany DYSMAS Project Agreement.

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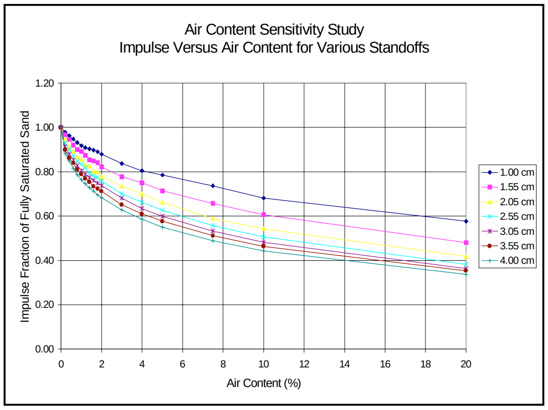

Figure 1. Air Content Sensitivity Study

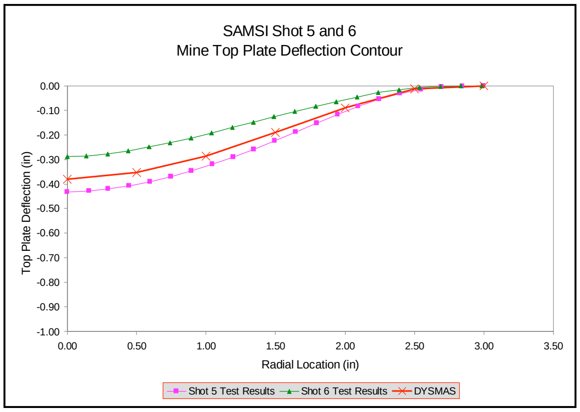

Figure 2. SAMSI Simulation Results Versus Test Results

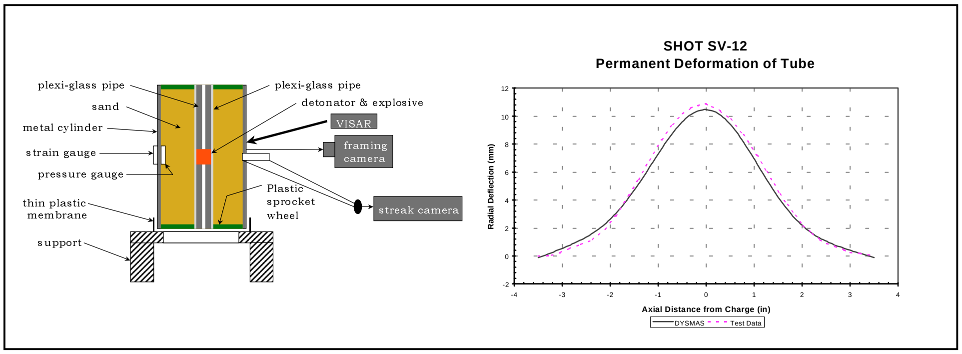

Figure 3. Sand Cylinder Test Schematic and Validation Simulation Results