Surf Zone Explosive Channel Modeling

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LONG-TERM GOAL

The long-term goal of this project is to develop a reliable and robust predictive methodology of general applicability for predicting the sizes of craters and channels produced in the surf zone by underwater explosions of single bombs, lines of bombs, and line charges. These predictions will be used in the mine and obstacle-breaching strategy of forming clear channels approaching the beach for use by amphibious assault vehicles.

OBJECTIVES

There are two primary objectives required to meet our long-term goal. The first is to simulate the long-time hydrodynamics of the cratering (or channeling) process using an incompressible hydrocode. This code will include multi-species (sand and water) capability with an appropriate constitutive model describing the mechanical properties of saturated sand. Validations will be made by comparisons with underwater explosion experiments performed using a variety of sands and explosive types over a large range of size scales. Once validated, these code simulations will provide a better understanding of the phenomenology associated with explosive cratering and provide a tool to supplement the experimental database, which will then be used to develop analytical models.

The second objective is (1) to assemble a database of full size and small scale experimental results; (2) to identify those properties sufficient to account for variations of water and burial depths and bottom soil and explosive types using controlled test data supplemented with code simulations; and then (3) to develop an empirical fit of this data using dimensionless similitude parameters of the independent and dependent variables which will scale these results and thus provide a quick means of estimating crater and channel sizes.

APPROACH

The general approach to achieve this goal is to generalize and apply the Naval Research Laboratory (NRL) incompressible hydro-code BUB to model bottom soil excavation by the explosion's bubble

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expansion. This code may require that the initial conditions, produced by the detonation's shock wave effects, be provided by a compressible code such as CTH. The BUB code will then be developed and applied to model the results of one-g, small-scale tests conducted by the University of Maryland (UMd), which, in combination with higher-g tests (also by UMd) and limited full scale tests, will then validate the code modeling. The validated code will then supplement the empirical database for developing the predictive similitude scaling methodology.

Dr. Szymczak (NRL) is responsible for developing material models for saturated sand and incorporating them into his hydrodynamic codes BUB2D (for two-dimensional and axi-symmetry) and BUB3D. The success of these codes in predicting the long-time dynamics of explosion bubbles in water only may be found in References [1] and [2]. Both multi-species capability (sand and water) and the equations modeling the visco-plastic deformation (flow) of the sand must be incorporated. A hierarchy of models for the material properties of sand will be developed. A large sample of controlled small scale experimental results will be provided in a cooperative task headed by Prof. W. Fourney at the UMd, for both validation purposes and increasing the size (and hence robustness) of the database.

Stephen Van Denk (NSWC Indian Head) is responsible for constructing a database of underwater explosion (UNDEX) cratering and channeling test results, as well as formulating scaling laws and developing the empirical relationships for predictive purposes. The general approach in formulating the scaling law follows that used in prior work for dry soil cratering documented in Reference [3]. In that work the similitude parameters for single charge cratering developed by P.S. Westine in Reference [4] were generalized for a line row of bombs or line charges using the Buckingham Π technique as illustrated in Reference [5]. In the present case, these similitude parameters are generalized to include the water overburden, which will then be correlated to the database to form the scaling laws for crater and channel size. The database will be assembled as a software spreadsheet for the computation of similituded parameters per test entry. This spreadsheet will then be accessed by a relational database software to allow selective correlation of parameters, say of two parameters for those tests in which the other parameters are constant, or nearly so.

WORK COMPLETED

A multiple-species formulation of the hydrodynamic theory embedded within the BUB codes has been completed, analyzed, and implemented efficiently into the two-dimensional code BUB2D.

A visco-plastic flow model (Bingham) has been implemented into the two-dimensional code. This model has two parameters, one related to a flow viscosity and the other corresponding to a shear strength. Only when this strength of capillary coheson and sliding friction is exceeded will the material (saturated sand) flow. In this way, permanent deformations in the sand are possible whenever the shear stresses fall below the shear strength.

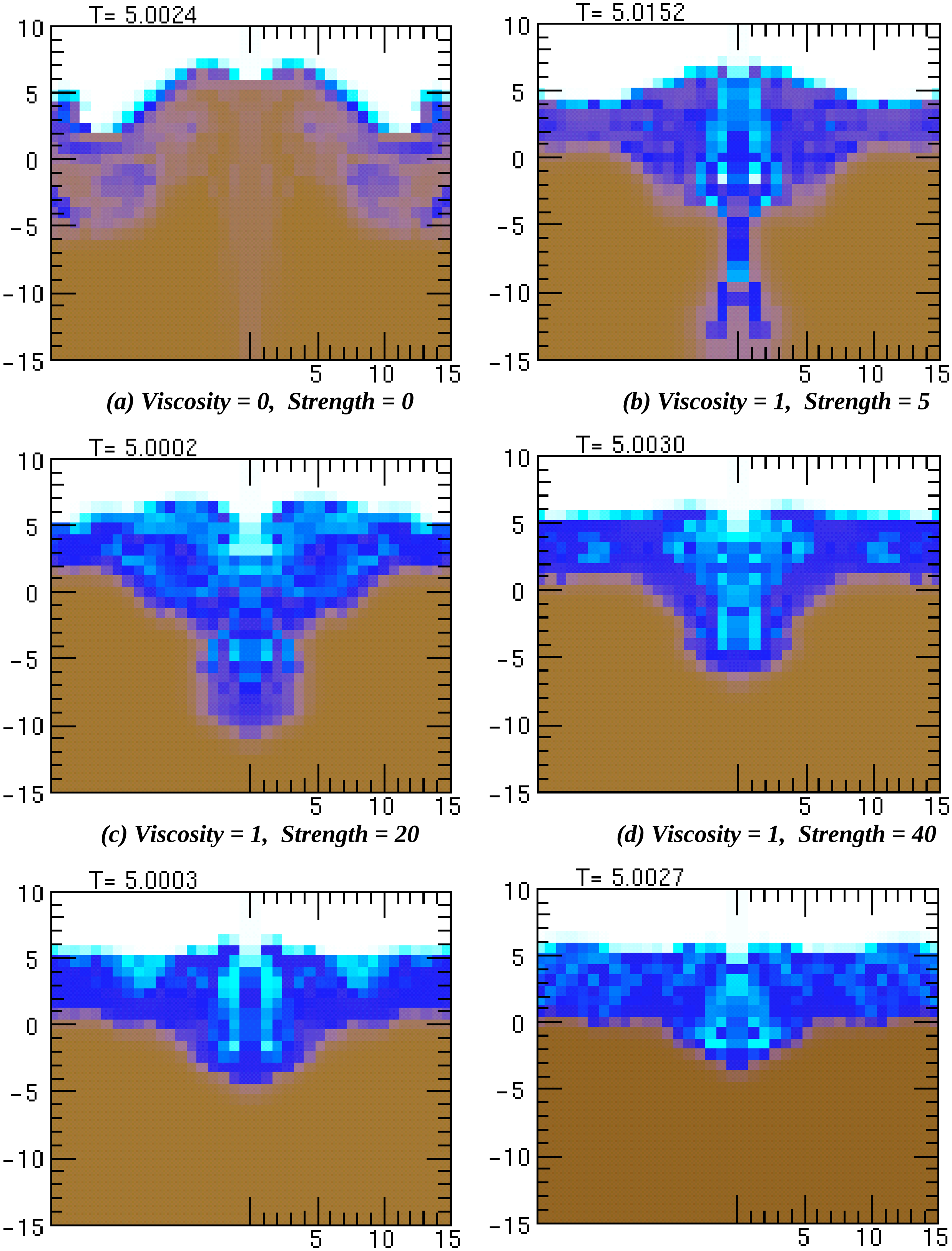
Improvements in the predictive capability of the code were made for the case of explosions in very shallow water (where the charge depth is less than half of the free-field maximum bubble radius). This situation is typical for surf zone environments. It is important to be able to reliably predict these cases due to large qualitative differences in the overall dynamics if the bubble vents during its first expansion.

A database of cratering results has been assembled in a Microsoft Exel™ spreadsheet for all known UNDEX tests up to 1996. The similitude parameters for the general case of a water overburden have been formulated for a three parameter bottom soil mateial properties characterization.

A series of tests at intermediate scale (8 lb charges) was conducted at the Proof and Experimental Establishment (P&EE), Port Wakefield, Australia. Twelve cratering tests were conducted at various water and burial depths as well as one four charge channeling test.

RESULTS

A computational investigation using the viscous-plastic flow model in BUB2D was made. The simulation of a line charge of 4.2 lbs/ft of PE6-A1 explosive laid on the bottom and covered by 5 ft of water was run since the results of a test with this configuration were described in Reference [6]. Figure 1 shows the density contour plots of the computed final channel profiles (approximated as 5 seconds after detonation) using different values of flow viscosities and shear strengths. In these plots the sand is colored brown, the water blue and the air and bubble are white. The tick marks on the plot edges are in units of feet. When there is no viscosity or shear strength (Figure1, case (a)) the channel rebounds forming a central berm. Of course this berm would eventually flatten out since the sand is simply a dense liquid in this case. With a relatively low viscosity and strength (Figure1, case (b)) the channel persists and has a narrow deep groove down the center caused by the water jet (actually a water "sheet") which forms during the bubble's first collapse and impacts the bottom of the channel. This narrow channel eventually closed up, and the crater became partially filled as the computation was carried further. With higher strengths, in runs (c) and (d), the channels became effectively rigid after the excavating influence of water jet impact. In these cases the jet increased the depths of the channel, by over 5 ft. in case (c) and approximately 3 ft in case (d). With a higher viscosity, cases (e) and (f), the sand had greater resistance to flow and the resulting channels were very stable, and were only slightly deepened by the water jet. The result in case (e) provided the best qualitative agreement with the observed channel displayed in Reference [6], which had a width of 8.2 m (26.9 ft) and depth of about 0.76 m (2.5 ft). Unfortunately, the berm has not been accurately reproduced in these computations (except possibly case (c) which shows the sand 2 ft above its initial level).



(a) Viscosity = 0, Strength = 0

(b) Viscosity = 1, Strength = 5

(c) Viscosity = 1, Strength = 20

(d) Viscosity = 1, Strength = 40

(e) Viscosity = 10, Strength = 20

(f) Viscosity = 10, Strength = 40

Figure 1. Late time channel profiles for different flow viscosity and shear strength values.

IMPACT/APPLICATION

Accurate predictions of surf zone channeling can be used to optimize mine field breaching strategies. As a result of this research accurate means for determining the required charge weight as well as the optimum conditions of placement (burial depth and spacing) for the given conditions of bottom soil and explosive types and water cover depth necessary for obstacle and mine clearance and channeling to the beach will be available.

An additional spin-off of this work may possibly be in the area of beach erosion. In addition to the Bingham plastic modeling currently under investigation, more complex models which will better predict sedimentation and the flow of water through the sand are being investigated. It is hoped that these models will provide for realistic simulations of a wide variety of surf zone applications.

TRANSITIONS

There have been no transitions as yet. However, it must be noted that the Naval Studies Board (NSB) strongly recommends explosive channeling as its “bold approach” to the surf zone minefield breaching.

RELATED PROJECTS

As discussed above the work being performed by the University of Maryland, under Grant # N000149810045, for which Prof. W.L. Fourney is the principal investigator, is dirctly related to this task. Also, if detonation shock compressibility effects prove to be significant in cratering, then the dynamic constitutive modeling of satuated sand bottoms by D. Tam, under Award # N0001498WX30032 would be used in a compressible code as a precursor to the use of the BUB code. Additionally, the on going efforts by Dr. L.D. Bibee of NRL on bottom materials characterization is applicable to this task.

REFERENCES

J.C.W. Rogersand and W.G. Szymczak, 1997: “Computations of violent surface motions: comparisons with theory and experiment,” *Phil. Trans. R. Soc. Lond.*, A, 355, 649-663.

W.G. Szymczak and C.E. Higdon, 1998: “Model validations and predictions for water barrier defense”, Naval Research Laboratory Formal Report, NRL/FR/7130-98-9880.

D. Nell, D. Betancourt, and S. Van Denk, 1996: *Explosive Cratering and Channeling of Shallow Water Bottoms*, NSWCIH TR 1924, 30 Sep.

P.S. Westine, 1970: “Explosive Cratering”, *J. of Terramechanics*, Vol. 7, No. 2, 1970, pp. 9-19.

W.E. Baker, P.S. Westine and F.T. Dodge, 1991: *Similarity Methods in Engineering Dynamics / Theory and Practice of Scale Modeling*, Revised Ed., Elsevier Science Publishers, pp 239-248.

L.C. Taylor and F.W. Furr, 1997: “Report on joint UK-US tests conducted at DERA Weston-Super-Mare,” 10-19 September 1996, Enclosure (7).