# Distributed Explosive Performance Model

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## LONG-TERM GOALS

Our goal is to provide a vital capability in modeling and simulation of performance of distributed explosives in the surf zone environment. This will allow for tradeoffs of system design parameters without the need for time-intensive computations and/or full-scale testing. We will deliver a product in form of a personal computer-based analytic code, which will assess the effectiveness of surf zone mine clearance systems such as explosive cord arrays (DET) and linearly distributed bulk charges (SABRE).

## OBJECTIVES

We wish to examine the effects of the design, deployment, and environmental parameters on the performance of distributed explosives on a sand bottom in the surf zone. In infinite water, it is possible to use a hydrocode-generated database to derive simple analytic expressions for the performance of distributed explosives. These are similar to the similitude equations for bulk charges. When the bottom sand and air are introduced, it is no longer possible to develop such analytic expressions. Therefore, we have developed a model to manipulate a multi-dimensional computational database using a PC-based analytic code to obtain the required information.

## APPROACH

We have focused our efforts in developing a model for Distributed Explosive Performance (DEP) on generating computational free field pressures, impulses, and energies (response index). A response index contains free field pressures, impulses, and energies as a function of selected parameters such as depth in water and sand, charge weight/separation, charge type, and placement variation. A database of performance is then established. Using scaling laws[1], Figure 1, we correlate the performance as a function of the parameters. Therefore, we are developing the analytic model based on the results generated from hydrocode (CTH) analysis. Figure 2 shows a sample computational result. The CTH analysis provides the spatial and temporal distributions of the performance variables that reflect the physics of the surf zone environment, i.e., CTH incorporates appropriate constitutive relations such as material equations of state for the air, water, explosive, and sand model. We are implementing the DEP model in a PC-based FORTRAN computer program called Distributed Explosive Performance

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Analytic Code (DEPAC). DEPAC is a restructured and an upgraded one-stop code of the previous version of the Linear Explosive Array Performance (LEAP) and Line-charge Analytic Model (LAM)[2, 3].

Scaling Laws for Distributed Explosives in Surf Zone (Similitude Equations)

$$P' = \frac{P}{P_o} \frac{L_s}{\sqrt{A}}; \quad I' = \frac{I}{P_o} \frac{C_o}{\sqrt{A}}; \quad E' = \frac{E}{P_o} \frac{L_s}{A};$$

$$Z' = \frac{Z}{L_s}; \quad T' = T \frac{C_o}{L_s}$$

where P', P = scaled and actual pressures, respectively
$L_S$ = charge spacing
A = cross-sectional area - single charge
$P_o = D_o C_o^2$ = bulk modulus of the ambient water
$D_o$ = mass density of the ambient water
$C_o$ = sound speed in the ambient water
z', z = any scaled and linear dimensions, respectively
T', T = scaled and actual times, respectively.

***Figure 1. Scaling Laws for Distributed Explosive***

Computational Database Support

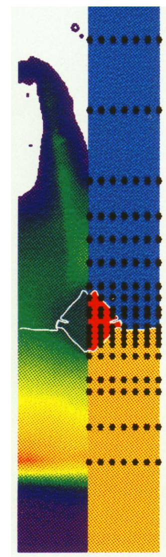

***Figure 2. Sample Computational Output***

## WORK COMPLETED

In previous years (FY92 through FY97), we accomplished the following:

1. Conducted time-intensive computations to investigate the performance of distributed explosives in the surf zone[2, 4].
2. Developed the Scaling Laws for distributed explosive based on our findings[1].
3. Developed the initial version of DEPAC (LEAP and LAM)[3].
4. Released three Technical Results (TRs).
5. Established the methodology for quick-response assessment of performance of distributed explosives in the surf zone[1, 2, 4, 5].

Based on this methodology and the use of immature technology initially, mostly related to constitutive relations, e.g., sand model, Equation of State (EOS) for explosive, etc., it became necessary to upgrade the DEP model in FY98 to incorporate a more matured technology. Hence, in FY98, we conducted a lot of CTH runs (parametric study), using improved technology, to establish the aforementioned response index. This parametric study includes modeling both infinite detcord arrays and line charges. To reduce the chance for error and to prevent the tedium of repetitive runs, an automated scheme (pre and post processors) was developed to create the input files for each run for CTH, process the data generated by CTH, and create the input database files for DEPAC.

The line charge is composed of equally spaced discrete (lumped) charges. The CTH analysis of the line charge modeled just one of the discrete charges, not the entire line. A superposition method[5] was developed to compute the superposition of pressure-signatures from discrete line charge using results from a 2-D axi-symmetric CTH analysis of a lumped charge. A linear superposition method was developed to simulate a 3-D analysis of discrete line charge.

In FY98, the DEP task also conducted a series of investigations that led to the implementation of a 1-D hydrocode based higher order godunov algorithm (1d_god) in DEPAC. 1d_god will be used as an analytic expression to address a wide variety of explosives and world beaches. It will be used to augment the hydrocode database in DEPAC; the latter only addresses one explosive and one beach. 1d_god was developed by Dr. Andrew Wardlaw, Naval Surface Warfare Center, Indian Head Division. It was modified and customized for implementation in DEPAC. The 1d_god numerical method solves the Euler equations in 1-D, in Cartesian, Cylindrical or Spherical Coordinates using a second order Godunov Method. The flow field can contain multiple materials, which are assumed to be separated by sharp interfaces. Currently the following material types are supported: JWL, Tait, MieGrueneisen, HOM, P-$\alpha$, and “user_defined”.

## RESULTS

The results of the computational runs consisted of multiple pressure histories recorded at fixed (tracer) points. These tracer points were placed at different locations in sand and in water. The independent variables are explosive cord weight, spacing, water depth, standoff, and air content. The dependent parameters (pressure, impulse, and energy) are related to both the cross-sectional area, A, of the explosive and the spacing, Ls. Using the bulk modulus of water and the sonic velocity in water as the reference pressure and velocity, respectively, the performance was non-dimensionalized.

We have implemented these results in DEPAC. Figure 3 contains a sample DEPAC output. The changes in DEPAC are extensive compared to the previous version of LEAP and LAM. A TR[5] is in progress that contains the User’s Manual for DEPAC as well as a detailed description of the FY98 effort. We will release DEPAC for distribution on CD-ROM when the TR is released. However, a beta version will be available earlier.

## IMPACT/APPLICATIONS

The DEP model is a quick-response predictive tool and technique that will enable the designer to choose design configurations (e.g., spacing, weight, explosive type, etc) in terms of output: pressure, impulse, and energy for various mine threats. It will help the designer quickly to predict performance and optimize a design against proud, buried and partially buried mines. Without this tool, every problem would be attacked with hydrocode analysis or with testing. While it is possible to deal with each case individually using a hydrocode, this is a lengthy, costly, and laborious process. The DEP model will predict line charge performance in shallow water. Although, methods exist to calculate line charge performance using similitude equations in free water, these methods are not adequate in shallow water and in the presence of a sand bottom.  Therefore, the tool developed in this task is a very important element of a new initiative to develop simulation-based design models.

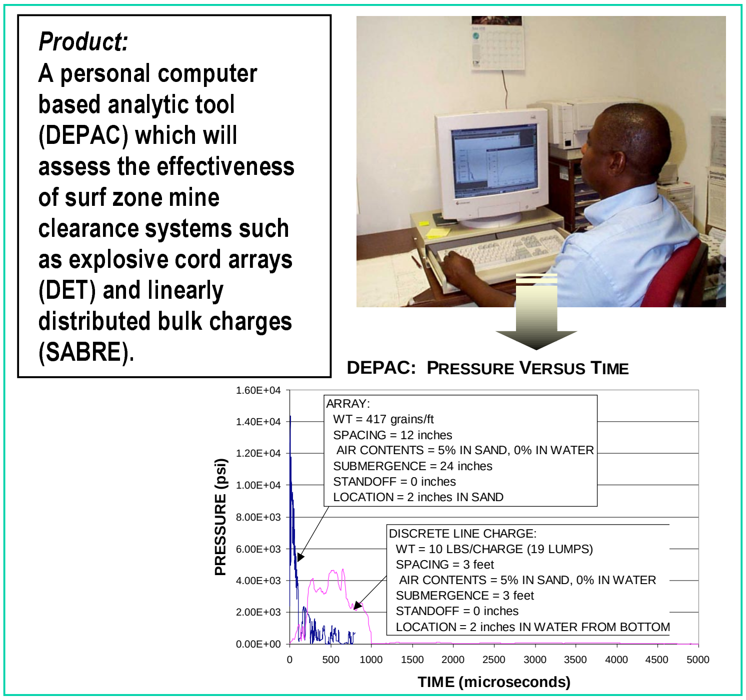


***Figure 3.  Sample DEPAC Output***

## TRANSITIONS

Information, improved models, and techniques are continually being transitioned to the system development programs of PMS-407.

## RELATED PROJECTS

The DEP model and threat mine vulnerability analysis will be used by the NAVSEA PMS-407 ENATD, DET, and SABRE programs as guidance for the shock loading levels which will be required to achieve neutralization of threat mines in the surf zone.  The Sand and Mine Response Task provided the P-$\alpha$ model.

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