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ADVANCED SEISMOLOGICAL RESEARCH AND IMPROVED YIELD DETERMINATION

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FINAL REPORT

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This report summarizes the work performed by S-CUBED involving the prediction of seismic coupling in salt, the analysis of tectonic release from underground explosions, the verification of constitutive models used to calculate ground motion in partially saturated brittle rocks, and the determination of the physical basis of two discrimination techniques.

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I. INTRODUCTION

The objective of the S-CUBED research program is to extend our present understanding of the generation, propagation detection and analysis of seismic waves by both underground explosions and earthquake sources. The goal is to improve the United States' ability to monitor compliance with treaties limiting the yields of underground nuclear explosions. This report covers work performed between 1 October 1981 and 30 September 1982 under Contract Number F08606-79-C-0008 (VSC Project VT/0712).

The specific topic addressed during this contract period was:

<u>Task 4.2</u> - The evaluation of suites of events in terms of our ability to predict the observed body waves and surface waves from those events which travel over previously uncalibrated paths.

In support of this task we have submitted five topical reports which are summarized in the next section.

II. THE EVALUATION OF SUITES OF EVENTS (Task 4.2)

During the contract period we have obtained seismic recordings from a sequence of explosions in a salt mine, completed the work on determining the physical basis of two discrimination techniques, synthesized the SALMON, GNOME and COWBOY ground motion data and then predicted the ground motion from a 200 pound charge of Pelletol explosive detonated in the Grand Saline Salt Dome, presented evidence that our constitutive models for effective stress and air void porosity adequately match ground motion data in partially saturated, brittle rocks, and completed an analysis of tectonic release from underground explosions. The topical reports, including abstracts, describing these results are as follows:

"SURFACE RECORDINGS OF PAI PHASE II EXPLOSIVE TESTS" by T. G. Barker SSS-R-82-5482.

Abstract

During the week of 15 February 1982, S-CUBED participated in Phase II of the sequence of explosive tests in salt carried out by Physics Applications, Incorporated (PAI). Our role in these tests was to monitor the seismic ground motions at distances from 1 to 16 kilometers and to determine the dependence of peak velocity, signal shape and spectral components on range, azimuth and explosion type. The tests consisted of two Nitromethane explosions with yields 200 and 70 pounds and one Pelletol explosion at 200 pounds. These shots, along with a mining blast, were monitored along two azimuths 100 degrees apart at ranges from 1 to 16 kilometers. This report describes our data acquisition procedures and offers preliminary analyses of the data.

The results may be summarized in the following figure which shows peak velocities as functions of range for the explosions that were monitored. The 70 pound shot has been scaled to 200 pounds.

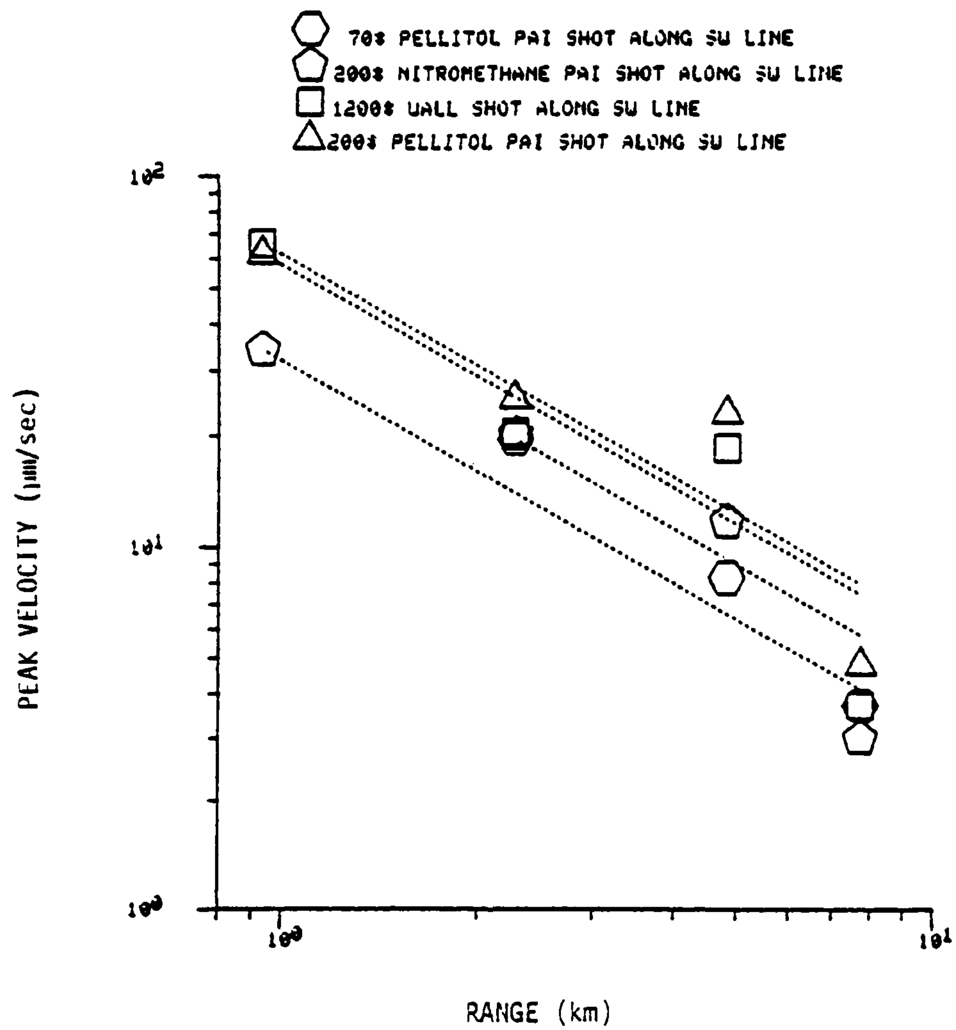

Figure 1. Peak velocity is plotted versus range. The 70 pound shot has been scaled to 200 pounds (scale factor 2.96). The dotted lines are at slopes of r^{-1} commencing at the closest range for each event.

"THE PHYSICAL BASIS OF m_b:M_s AND VARIABLE FREQUENCY MAGNITUDE METHODS FOR EARTHQUAKE/EXPLOSION DISCRIMINATION" by J. L. Stevens and S. M. Day, VSC-TR-82-24 (SSS-R-82-5595).

Abstract

We analyze the theoretical basis for the m_b:M_s and Variable Frequency Magnitude (VFM) earthquake/explosion discriminants in light of recent results from numerical modeling of earthquake and explosion dynamics. We examine the effects of source mechanism (double-couple versus point dilatation), source depth, source spectra, and source region elastic structure. We use six three-dimensional finite difference simulations of earthquakes for the earthquake source models, and four empirical (Mueller-Murphy) and four numerical models for explosions in different materials. We estimate that source mechanism (i.e., quadrupole versus monopole) contributes about 0.35 magnitude on the average to the separation between earthquakes and explosions on a m_b:M_s diagram. Differences in source region elastic properties tend to increase the separation, contributing a factor of approximately $\sqrt{\rho\alpha^3}$ (ρ = density, α = P-wave speed) to the ratio of surface wave amplitude to body wave amplitude. For events with $M_s < 4.0$, this effect may be more important than source spectral differences, especially for explosions in low velocity materials.

VFM discrimination depends primarily on spectral differences between earthquakes and explosions. Theoretical separation of the earthquake and explosion populations is very clear for explosions in granite at frequencies of 2 Hz or greater with $m_b > 4.0$. Smaller events may be discriminated using higher frequencies. Separation is not as good for explosions in low velocity materials such as tuff, especially at low yields.

For small events, the m_b:M_s and VFM discrimination methods work (or fail) for quite different reasons. Interference with pP causes earthquake and explosion populations to converge on the m_b:M_s plane at m_b 4.5 using an empirical depth/yield relation of $d = 122W^{1/3}$ meters. This interference increases the separation using VFM, allowing the method to work even for very low yields. More deeply buried small explosions may be discriminated by m_b:M_s, but not by VFM. Simultaneous use of both methods should allow improved discrimination.

"GROUND MOTION PREDICTIONS FOR THE GRAND SALINE EXPERIMENT" by N. Rimer and J. T. Cherry, VSC-TR-82-25 (SSS-R-82-5673).

Abstract

Finite difference calculations are used to predict the ground motion and RVP spectra from a tamped 200 pound charge of Pelletol explosive detonated in the Grand Saline Salt Dome. Computational constitutive models and material properties for dome salt are first normalized using ground motion data from a number of nuclear and high explosive events in salt including SALMON, GNOME, and COWBOY. The ground motion predictions for Phase III of the Grand Saline experiment are then made using our best guesses for site material properties. We predict an "elastic" radius between 17 to 23 meters and a final cavity radius of approximately 52 centimeters.

"VERIFICATION OF THE EFFECTIVE STRESS AND AIR VOID POROSITY CONSTITUTIVE MODELS" by J. T. Cherry and N. Rimer, SSS-R-82-5610.

Abstract

In this report, we present a severe test of the effective stress and air void porosity constitutive models by using them to simulate experiments in which small scale explosions were detonated in grout spheres. High quality reproducible particle velocity data were obtained from these experiments. We show that an effective stress law coupled with the irreversible collapse of air-filled porosity provide a very simple, straightforward explanation of this data. These results have served to reenforce our confidence in the validity of these models and their importance in determining seismic coupling.

"NONLINEAR MODELING OF TECTONIC RELEASE FROM UNDERGROUND EXPLOSIONS" by S. M. Day, J. T. Cherry, N. Rimer and J. L. Stevens, SSS-R-82-5555.

Abstract

Reversal of teleseismic Rayleigh wave polarity has been observed for some underground explosions in eastern Kazakh, and in some cases the polarity is reversed at all azimuths of observation. We analyze two-dimensional, nonlinear numerical simulations of underground explosions to examine the hypothesis that these phase reversals result from the action of tectonic prestress on the explosion-created nonlinear volume. We conclude that the effect of tectonic prestress on surface wave excitation is potentially large. When a shear prestress of 7.5 MPa (75 bars) is iintroduced, with horizontal principal stresses more compressive than the vertical principal stress, the explosion Rayleigh wave amplitude is reduced by a factor of 4 (i.e., M_s is reduced by 0.6). The large surface wave reduction is accompanied by no significant perturbation of the body wave magnitude (m_b). The nonlinear model predictions imply that if tectonic release is modeled elastically as the relaxation of the deviatoric part of the prestress into a spherical cavity, the appropriate cavity radius is approximately 80 percent of the explosion elastic radius.

Assuming that the explosion and tectonic release components of the source add linearly, i.e., assuming the surface wave reduction is proportional to the deviatoric prestress, then tectonic shear stress exceeding 10 MPa (100 bars) would be sufficient to reverse the Rayleigh wave polarity. Shear stresses of this magnitude are plausible at several hundred meters depth, in that they do not exceed strength bounds for a fractured rock mass, as estimated from Byerlee's law. Therefore, this hypothesis should be tested through further two-dimensional nonlinear modeling at higher prestress levels.