Conf-9107105--55

UCRL-JC--105861

DE92 002656

TI

NOV 12 1991

COMPARATIVE YIELD ESTIMATION VIA SHOCK HYDRODYNAMIC METHODS

A. Attia
B. Moran
L. A. Glenn

This paper was Submitted to the Proceedings of the
American Physical Society Topical Conference on
Shock Compression of Condensed Matter
Williamsburg, VA. June 17-21, 1991

June 1991

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

COMPARATIVE YIELD ESTIMATION VIA SHOCK HYDRODYNAMIC METHODS

Armand V. ATTIA, Bill MORAN, Lewis A. GLENN

Lawrence Livermore National Laboratory*

Shock TOA (CORRTEX) from recent underground nuclear explosions in saturated tuff were used to estimate yield via the simulated explosion-scaling method. The sensitivity of the derived yield to uncertainties in the measured shock Hugoniot, release adiabat, and gas porosity is the main focus of this paper. In this method for determining yield, we assume a point-source explosion in an infinite homogeneous material. The rock EOS is formulated using laboratory experiments on core samples, taken prior to the explosion. Results show that increasing gas porosity from 0% to 2% causes a 15% increase in yield per $\text{ms}/\text{kt}^{1/3}$.

1. INTRODUCTION

The procedure for obtaining hydrodynamic yield estimates from measured CORRTEX R-t data has been described in detail¹. We assume that in a homogenous bounded material region, an initial energy deposited, as a point source, gives rise to a spherical shock front, propagating uniformly outward. The total initial energy deposited is assumed to remain in this bounded region. In *Similar Explosion Scaling*, measured Shock Front Range vs. Time, R(t) data, for two nuclear tests are compared for geologically similar media. Given the known yield in one test (*the standard*), the unknown yield in the other test is estimated using cube-root-scaling (See Section 3, below). In *Simulated Explosion Scaling*, the standard is determined by calculating the R(t) response of the medium, to a given yield, by modelling the constitutive behavior of the rock using shock-and-release experiments conducted on core samples. The former method has the advantage of being independent of computational assumptions, but is generally considered less accurate whenever emplacement details and material properties are not exactly duplicated. For other approaches to yield estimation, see the works by Moss² and Lamb³.

We first describe the EOS model employed for the rock in the simulated standard. We then show calculations that indicate the significant effect of shock Hugoniot, release adiabat, and gas porosity on yield estimates obtained by scaling emplacement-hole CORRTEX data.

2. EOS MODEL

The EOS was synthesized based on shock and release data obtained from plate-impact experiments on sample cores taken from the satellite holes⁴. Figure 1 shows shock Hugoniot states obtained by Furnish from samples for two events. Shock velocity (U_s) is plotted as a function of particle velocity (U_p). The figure also shows the results of piecewise-linear fits to the data. We note that for Event Y, data are available only for $U_s < 5 \text{ km/s}$. At high pressure, we have chosen $U_s - U_p$ data for Event Y identical to that of Event X.

The Grüneisen EOS can be written as:

$$P = P_H (1 - \Gamma\mu/2) + \Gamma p_e \quad (1)$$

where $\mu = \eta - 1$, $\eta = \rho/\rho_0$ is the compression, ρ is the density, ρ_0 is the reference (non-porous) density, e is the specific

FIGURE 1 - Shock Hugoniot Data

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract # W-7405-Eng-48.

internal energy, and Γ is the Grüneisen coefficient, representing the ratio of the thermal pressure to the thermal energy of the lattice. P_H is the Hugoniot pressure which, with a linear U_s-U_p relation, reduces to:

$$P_H(x) = \rho_0 c^2 x / (1 - sx)^2 \quad (2)$$

where $x \equiv \mu / (1 + \mu)$, and $c = U_s(0)$ and $s = dU_s/dU_p$.

We have chosen, for simplicity, $\Gamma = \Gamma(\rho)$ in the CORTEX analysis to date. The specific form employed for both events was developed by trial and error, using the Event X emplacement-hole CORTEX data as a basis set. Three independent inputs were also used. At normal density ($\eta=1$), we calculated $\Gamma=0.3$ as the molar-weighted average of the known values for water and pure silica. At $\eta=2.3$, we calculated $\Gamma=0.9$ from release data⁴ at a pressure of roughly 100 Gpa. And, for $\eta \rightarrow \infty$, we took $\Gamma=0.5$, based on Kopyshv's Thomas-Fermi calculation⁵. The final result was:

$$\Gamma(\eta) = \begin{cases} 0.3 & \text{if } 0 \leq \eta \leq 1; \\ -0.166 + 0.466\eta & \text{if } 1 < \eta \leq 2.060; \\ -3 + 3.218\eta - 0.668\eta^2 & \text{if } 2.060 < \eta < 2.409 \\ 0.5 + 1.809/\eta - 2.179/\eta^2 & \text{if } \eta > 2.409 \end{cases} \quad (3)$$

FIGURE 2 - Grüneisen coefficient model

Equation (3) is plotted in Figure 2. We note that, although the smooth transition shown for $1 < \eta < 2.3$ gave reasonably good agreement with experiment when porosity was introduced, this is by no means a unique solution. Some of the plate-impact experiments suggest that the effective Grüneisen coefficient could be negative in this interval.

in particular at pressures of 7-10 Gpa. This is thought to be the result of a Stishovite phase transition in the silica and is currently being investigated.

The presence of gas porosity can be introduced via the Grüneisen model by assuming that the *in situ* density is related to the reference density, ρ_0 , and porosity, κ , by the relation:

$$\rho(0) = (1 - \kappa) \rho_0 \quad (4)$$

For $\kappa > 0$, $\rho(0) < \rho_0$ and Equation (1) will return $P < 0$ unless ϵ is sufficiently high; i.e., tensile pressures will occur, in particular initially when the rock is not yet shock heated. To avoid this non-physical situation, we modify Equation (1) and set $P \equiv 0$ whenever a negative value is calculated. This procedure is equivalent to assuming the compressive strength of the porous rock to be negligible in comparison to the shock pressure.

3. EFFECT OF SHOCK AND RELEASE MODEL ON YIELD ESTIMATES

Figure 3 shows the effect of Hugoniot and Grüneisen models on yield estimates, when we assume no gas porosity.

FIGURE 3 - Effect of shock-and-release model on yield (Zero gas porosity)

We will first consider the effect of using Hugoniot Fits X and Y on the yield estimate, with the same Grüneisen form $\Gamma(\eta)$ given by Equation (3). Results are shown by Curves (1) and (2) in Figure 3. To understand these effects on the yield estimate, we turn to the method of estimating

yield. Now, in cube-root-scaling, we have, at a measured time t_i and measured shock position R_i :

$$W_{est}(t_i) = W_{sim} [R_i / R_{sim}(R_i / t_i)]^3 \quad (5)$$

where W_{sim} is the yield chosen in the simulation, $W_{est}(t_i)$ is the estimated yield at the measured time, and R_{sim} is the simulated shock position, which is evaluated at the ratio of measured position to measured time.

We now construct two *Simulation Standards* A and B, based on Hugoniot Fits X and Y, respectively, by performing the corresponding simulations of the explosion. Using these two standards, we will calculate two different yield estimates W_A and W_B for the *single unknown* event. Let R_A and R_B be the shock position predicted for each measured data point (t_i, R_i) by Simulation Standards A and B, respectively. Then, using Equation (5), we have:

$$W_A(t_i) = W_{sim} [R_i / R_A(R_i / t_i)]^3 \quad (5a)$$

and

$$W_B(t_i) = W_{sim} [R_i / R_B(R_i / t_i)]^3 \quad (5b)$$

Dividing Equation (5a) by Equation (5b), we find that at each measured data point:

$$W_A / W_B = (R_B / R_A)^3 \quad (6)$$

Equation (6) states that, given a *single unknown* event, when we use *two different standards* A and B to obtain yield estimates W_A and W_B , we will find these estimates to be *inversely proportional* to the predicted shock time histories, $R_A(t)$ and $R_B(t)$, respectively. We now apply Equation (6) to the yields obtained by using Hugoniot Fits X and Y. Note that, from Figure 1, the Fit Y Hugoniot gives a faster shock than the Fit X Hugoniot, for the same particle velocity, in the lower regime $U_p < 3$ km/s. Thus, Fit Y gives a more penetrating shock than Fit X and Equation (6) shows that Fit Y produces a *lower* yield than Fit X, as shown by Curves (1) and (2) in Figure 3.

We next consider the effect of increasing the Grüneisen coefficient Γ from a constant value of 0.2 to 0.5, but for the same Hugoniot (Fit X). Results are shown by Curves (3) and (4), in Figure 3. Since the shocked material expands spherically outward, unloading necessarily occurs immediately behind the shock front. This unloading is controlled by the Grüneisen coefficient. The Grüneisen EOS, Equation (1), shows that an increase in Γ results in reduced unloading, producing a stronger, more penetrating shock. From Equation (6), we find that if we increase the

Grüneisen coefficient, we will lower the yield estimate, as shown in Figure 3 by Curves (3) and (4).

4. EFFECT OF GAS POROSITY ON YIELD ESTIMATES

Figure 4 shows the effect of gas porosity on yield estimates.

FIGURE 4 - Effect of gas porosity on yield

Using the Grüneisen form in Equation (3) and the Fit X Hugoniot, we now increase the gas porosity from 0 to 2 %, and we find that the yield estimates increase accordingly. Since an increase in gas porosity causes an increase in attenuation of the shock front, we have $\kappa_A > \kappa_B$ implies that $R_A < R_B$ and, from (6), increasing gas porosity causes an increase in yield estimate.

5. CONCLUSIONS

We have shown that yield estimates are very sensitive to Hugoniot, release adiabat, and gas porosity. Such sensitivity indicates the need to obtain more accurate estimates for these parameters from core sample measurements.

We found that the predicted yield was significantly different when gas porosity was varied within the range: 0-2%. Current methods for measuring gas porosity *in situ* are insufficient to resolve this range, and laboratory density measurements on cores often exhibit large sample-to-sample variations; on Event X, for example, the density variations exceeded 1.5% with cores taken from a single satellite hole.

Another component of the EOS that is not well enough defined by either theory or experiment is the effective Grüneisen coefficient, Γ , which characterizes the ratio of thermal pressure to the thermal energy of the lattice. It has been shown that the yield is quite sensitive to both Γ and the shock Hugoniot. The latter is measured adequately by plate impact experiments in the laboratory, but these experiments accurately define Γ , at best, only along the Hugoniot. Away from the Hugoniot, release paths are found to lie very close or below the Hugoniot of the material, as observed by Swegle⁶. However, interpretation of these release adiabats and the results of extracting Γ from them are open to question because of possible metastability of the release states and rate effects during unloading. In the CORTEX analysis that has been done to date, Γ has accordingly been specified only as a function of density, the specific form relying on crude theory and a few plate-impact experiments. We are currently investigating possible experiments which would help to establish off-Hugoniot states.

ACKNOWLEDGEMENTS

We would like to acknowledge W. Moss, J. White, and R. Heinle for helpful discussions and for reviewing this paper.

REFERENCES

1. D.S. King, B.E. Freeman, D.D. Eilers, and J.D. Johnson, The effective yield of a nuclear explosion in a small cavity in geologic material: enhanced coupling revisited, *J. Geophysical Research*, v. 94, n. B9 (Sept. 1989), pp. 12375-12385.
2. W.C. Moss, A method to estimate the yield of an underground nuclear explosion, *Proc. of the APS Topical Conference on Shock Waves in Condensed Matter* (1987), pp. 243-246.
3. F.K. Lamb, B.W. Callen, and J.D. Sullivan, An approximate analytical model of shock waves from underground nuclear explosions, submitted to *Journal of Geophysical Research*, December 1990.
4. M. Furnish, Dynamic properties of rocks and grouts pertinent to the HYDROPLUS program, Sandia National Laboratory Report, 1991 (in press).
5. V.P. Kopyshov, Grüneisen constant in the Thomas-Fermi approximation, *Sov. Phys. Doklady*, v. 10, n. 4 (Oct. 1965), pp. 338-339.
6. J.W. Swegle, Irreversible phase transitions and wave propagation in silicate geologic materials, *Proc. of the APS Topical Conference on Shock Compression of Condensed Matter* (1989) pp. 147-150.

END

**DATE
FILMED**

01/103/192