SAND2012-10345P

Finite-Difference Numerical Simulations of Underground Explosion Cavity Decoupling

David F. Aldridge, Leiph A. Preston, and Richard P. Jensen

Geophysics and Atmospheric Sciences Department, Sandia National Laboratories, Albuquerque, New Mexico

Introduction and Summary

Earth models containing a significant portion of ideal fluid (e.g., air and/or water) are of increasing interest in seismic wave propagation simulations. Examples include a marine model with a thick water layer, and a land model with air overlying a rugged topographic surface. The atmospheric infrasound community is currently interested in coupled seismic-acoustic propagation of low-frequency signals over long ranges (~10s to ~100s of kilometers). Also, accurate and efficient numerical treatment of models containing underground air-filled voids (caves, caverns, tunnels, subterranean man-made facilities) is essential.

In support of the Source Physics Experiment (SPE) conducted at the Nevada National Security Site (NNSS), we are developing a numerical algorithm for simulating coupled seismic and acoustic wave propagation in mixed solid/fluid media. Solution methodology involves explicit, time-domain finite-differencing of the elastodynamic velocity-stress partial differential system on a 3D staggered spatial grid. Conditional logic is used to avoid shear stress updating within fluid zones; this approach leads to computational efficiency gains for models containing a significant proportion of ideal fluid. Numerical stability and accuracy are maintained at air/rock interfaces (where the contrast in mass density is on the order of 1 to 2000) via a finite-difference operator "order switching" formalism. The 4th-order spatial FD operator used throughout the bulk of the earth model is reduced to 2nd-order in the immediate vicinity of a high-contrast interface.

Current modeling efforts address the so-called cavity decoupling problem, where an underground explosion is detonated within an air-filled void. A point explosion source located at the center of a spherical cavity generates only diverging compressional waves. However, we find that shear waves are generated by an off-center source, or by a non-spherical cavity (e.g., a tunnel). Strong resonant signals, formed by repeated reflections at the air/rock interface, are a diagnostic feature of cavity decoupled explosions.

Seismic Wave Equations and 3D Finite-Difference Grid

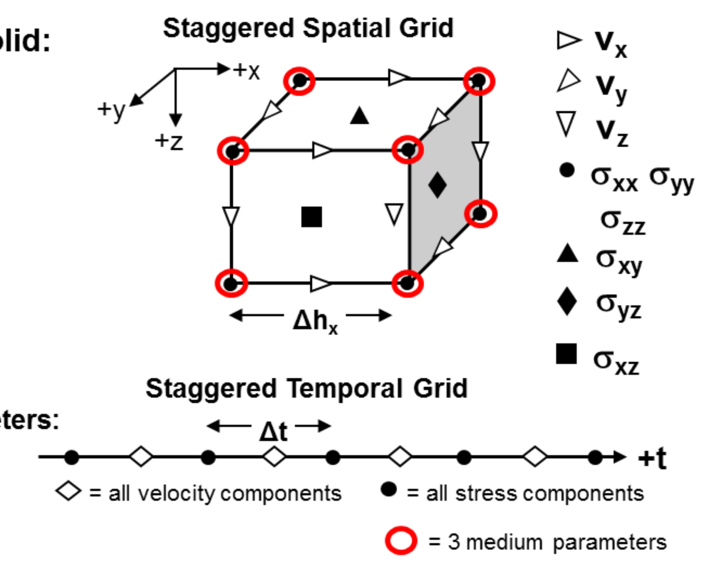
Isotropic Elastic Solid: 9 wavefield variables + 3 medium parameters

Velocity-Stress System **for Isotropic Elastic Solid:**

Nine, coupled, first-order, inhomogeneous, partial differential equations:

$$\rho \frac{\partial \mathbf{v}}{\partial t} - \nabla \cdot \boldsymbol{\sigma} = \mathbf{f} + \nabla \cdot \mathbf{m}_{asm}$$

$$\frac{\partial \boldsymbol{\sigma}}{\partial t} - \lambda \left(\nabla \cdot \mathbf{v}\right)\mathbf{I} - \mu \left(\nabla \mathbf{v} + \nabla \mathbf{v}^{T}\right) = \frac{\partial \mathbf{m}_{sym}}{\partial t}$$

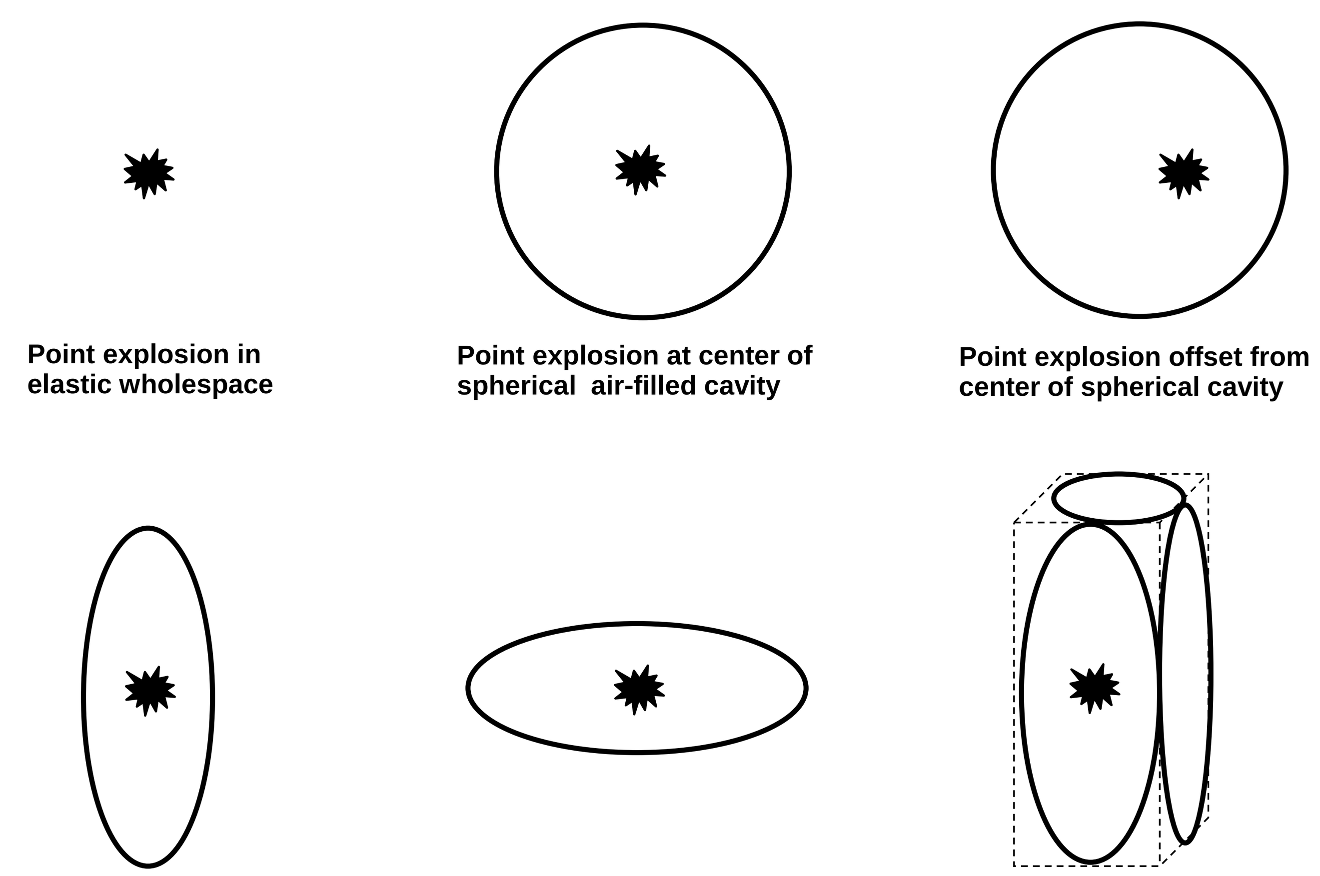


Wavefield Variables:
- $\mathbf{v}(\mathbf{x},t)$ – velocity vector
- $\sigma(\mathbf{x},t)$ – stress tensor

Elastic Earth Model Parameters:
- $\rho(\mathbf{x})$ – mass density
- $\lambda(\mathbf{x})$ – Lamé coefficient
- $\mu(\mathbf{x})$ – shear modulus

Seismic Body Sources:
- $\mathbf{f}(\mathbf{x},t)$ – force density vector
- $\mathbf{m}(\mathbf{x},t)$ – moment density tensor (with symmetric and asymmetric parts)

Six Seismic Energy Source Styles (not to scale)



Point explosion in elastic wholespace

Point explosion at center of spherical air-filled cavity

Point explosion offset from center of spherical cavity

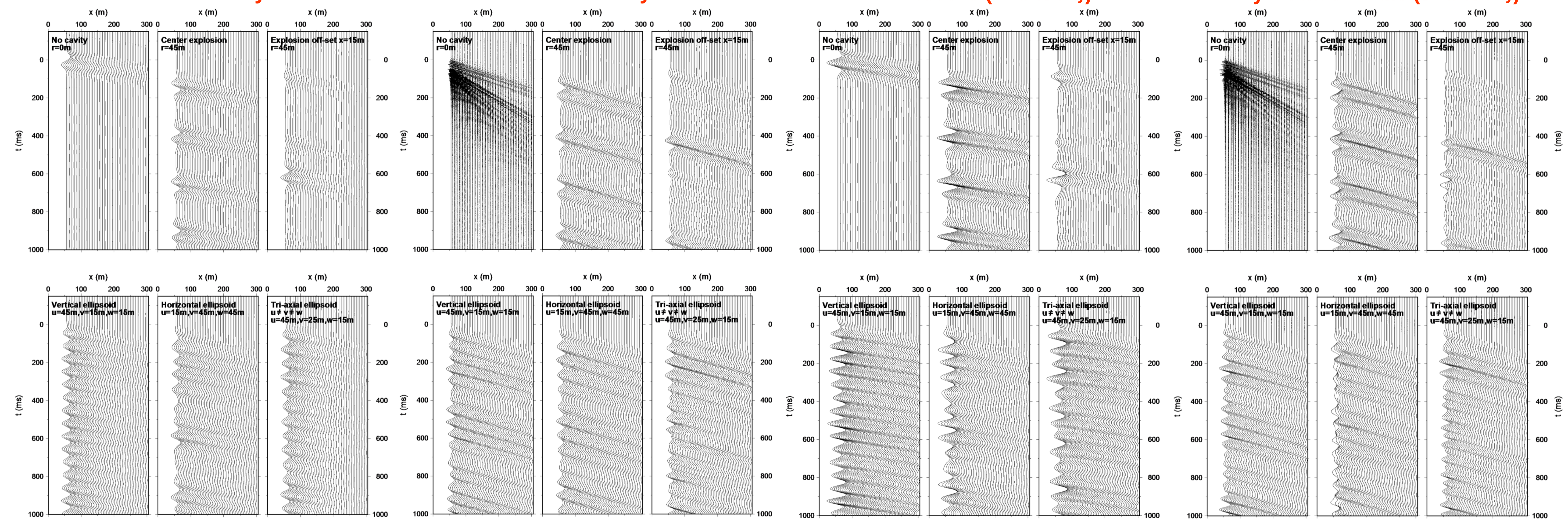
Vertical prolate ellipsoid (cigar)

Horizontal oblate ellipsoid (pancake)

Triaxial ellipsoid

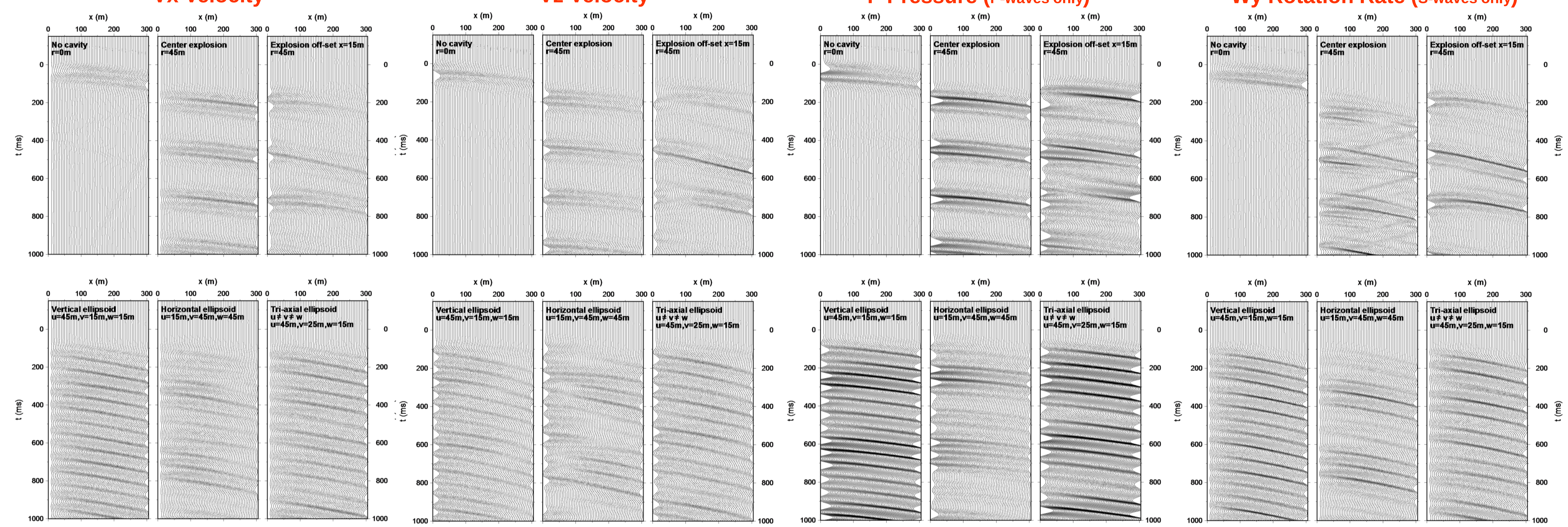
Homogeneous and Isotropic Elastic Wholespace: Synthetic Responses Observed on a Horizontal Receiver Array

Vx Velocity | **Vz Velocity** | **P Pressure (P-waves only)** | **Wy Rotation Rate (S-waves only)**



Air Halfspace Overlying Elastic Halfspace: Synthetic Responses Observed on a Horizontal Surface Receiver Array

Vx Velocity | **Vz Velocity** | **P Pressure (P-waves only)** | **Wy Rotation Rate (S-waves only)**



Acknowledgements

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly-owned subsidiary of Lockheed Martin Corporation, for the US Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

This research is supported by the National Center for Nuclear Security (NCNS) program office within DOE's National Nuclear Security Administration.