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TITLE SEISMIC SIGNALS FROM ASYMMETRIC UNDERGROUND NUCLEAR EXPLOSIONS

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Seismic Signals from Asymmetric Underground Nuclear Explosions

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Abstract

The methods discussed here, to estimate the effect on the seismic signals from asymmetric underground nuclear explosions, depends on the use of large-scale numerical codes and high-speed computers. We will discuss the use of a two-dimensional (2D) radiation diffusion coupled Eulerian hydrodynamic code (SOIL) for the early time phenomenology. The results from this calculation are then coupled into a 2D Lagrangian code that treats the strength of the materials and the effects of fractures, ground reflections and spalls. The final step in the simulation is the use of a seismic code (which uses the representation theory) to develop the actual far field seismic signals. These calculations were run on the CRAY YMP computers at the Los Alamos National Laboratory.

The asymmetric source that we are simulating is caused by the explosion of a nuclear device in a standard geometry 12-meter long canister but with complications from a partition in the canister that separates the source region from the remaining volume of the air filled canister. This geometry produces a strongly asymmetric two-lobed source in the hydrodynamic regime.

The radiation from the source is treated in the equilibrium diffusion approximation. This approximation allows for an approximate treatment of the wall blow-off. After the effects of radiation flow have abated, the radiation is turned off and the Eulerian hydrodynamic calculation is continued until a time of a few milliseconds and before the strength of the materials become important.

The results of this calculation are then coupled into the Lagrangian code for continuation to late times (2 seconds). The Lagrangian code treats the strength of the geological material as well as its yield strength, porosity, fracturing, and spalling. The initial calculation treated porosity as simply a difference of the *in situ* density and the normal density of the material.

Finally the tractions and displacements along a cylindrical surface, outside the inelastic region, are used as input to a code that uses the representation theorem to generate seismic signals at teleseismic distances.

1. INTRODUCTION

Seismic signals generated by nuclear explosions in cavities are studied using numerical techniques and large computers to solve the set of nonlinear differential equations. If the cavity is large enough, a decoupling effect occurs that decreases the size of the seismic signal. If the cavity is not symmetric, for instance, the explosion occurs in a tunnel or long canister, the resulting signal could also be distorted in direction and, therefore, affect the seismic signals. We study the effect of this geometric distortion utilizing first a 2D radiation diffusion Eulerian hydrodynamics code (SOIL), to estimate the early time effects due to radiation deposition and large shear motions in the hydrodynamics (Section 2) and then we discuss the coupling of these results to a strength of material Lagrangian code (CRAM, Section 3) and finally we use these results to calculate seismic signals utilizing the representation theorem (Section 4). This method of coupling codes was tested out on a spherical cavity decoupling problem, which along with results of the asymmetric study, and our conclusions will be given in Section 5. The results of this study show that the effect of an asymmetric explosion source, of the type modeled in this study, has no observable effect on the far field body waves from the explosion. Two factors are responsible for this effect: the initially asymmetric source becomes more symmetric as the shock propagates through the nonlinear regime; and the dominant frequency of the far field body wave is low enough that it is insensitive to details of the explosion source.

2. EARLY TIME MOTIONS

To handle the large distortions and radiation transport that occurs at early times in the detonation of a nuclear explosive in a tunnel or canister, we utilize a 2D equilibrium diffusion Eulerian hydrodynamics code (SOIL). The diffusion approximation, with an appropriate flux limiter, is used to calculate the flow and deposition of radiation from the hot source. This radiation dominated phase is over in a few microseconds and the radiation calculation can be turned off. To treat the large distortions caused by shear flows that resulted from the heated materials, especially in the corners of the canister, an Eulerian hydrodynamic scheme is used. In our asymmetric calculation a steel plate inside a standard emplacement geometry canister separates the source region from the rest of the air filled canister producing the density distribution at 0.1 msec shown in Figure 1. The pressure distribution developed in this asymmetric cavity, at the time of transfer to the Lagrangian mesh, is also shown in Figure 1 (9 msec). A simpler spherical cavity

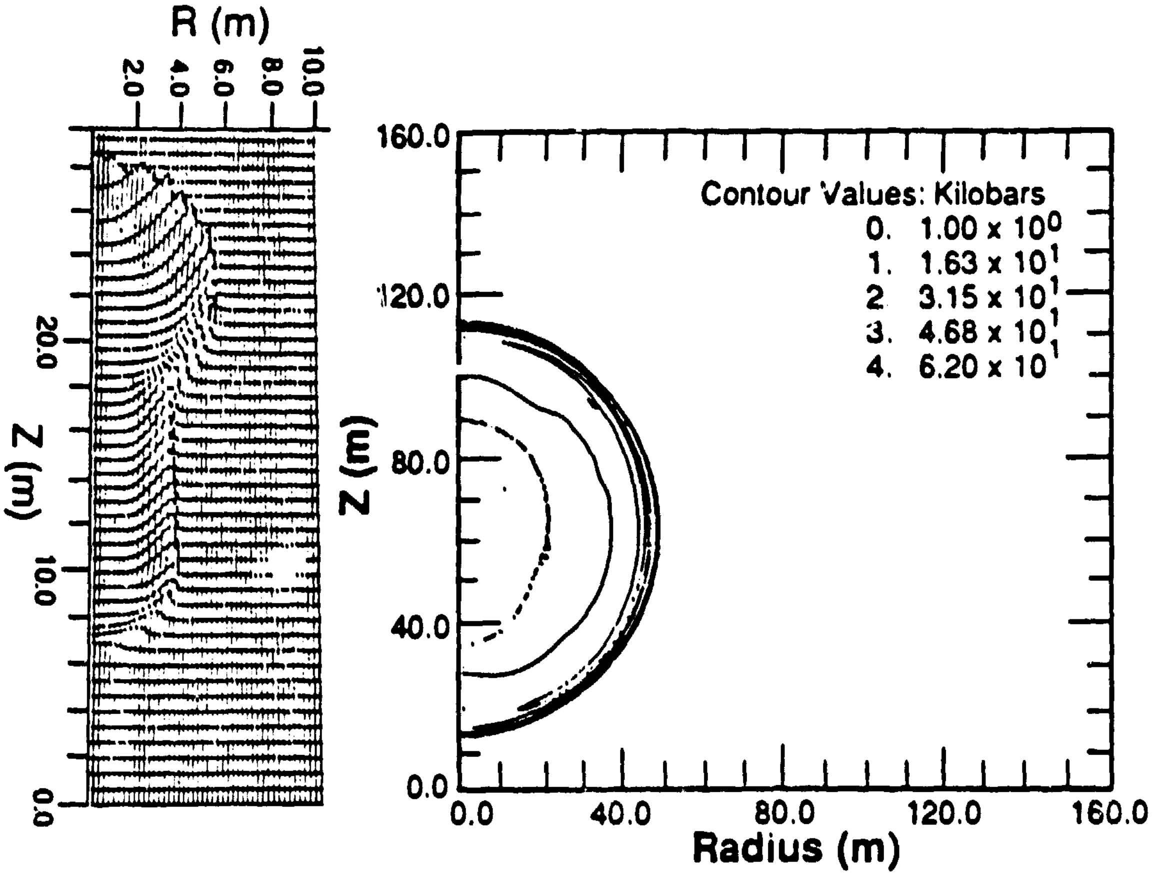

Fig. 1. Density profiles at 0.1 msec and pressure profiles at 9 msec from the SOIL calculation. The asymmetric source results from placing the explosion at the top of the canister with a heavy steel plate beneath it.

geometry (32 meter radius) was used as a test of the method, and the results from these calculations will also be presented in Section 5.

3. CODE COUPLING AND THE STRENGTH CALCULATION

Our next step in developing a seismic signal from the aforementioned asymmetric or symmetric source calculation is to couple these results into a strength of material Lagrangian hydrodynamic code (CRAM). At this time most of the large mesh distortions from shear flow have been removed, the radiation transport of the source energy has been completed, and the effects of porosity have been added by simply using a density ratio approximation in the equation of state (4.15% porosity). The Eulerian mesh results have to be carefully adjusted to the Lagrangian mesh to [illegible] a stable regime in the gravitational field before adding the source terms to the [illegible] field. Nonphysical signals could result from an improper joining of the early Eulerian results into the Lagrangian mesh. This late time strength dominated regime is then carried out using CRAM to 2 seconds, at which time the flow field becomes elastic. The results of displacement and normal stresses (tractions) along a cylindrical surface located near the edge in the Lagrangian mesh are stored for use in our next step of the calculation. The cavity shape at the transition from SOIL to CRAM (9 msec) along with the cavity size used in the spherically symmetric tamped calculation are shown in Figure 2.

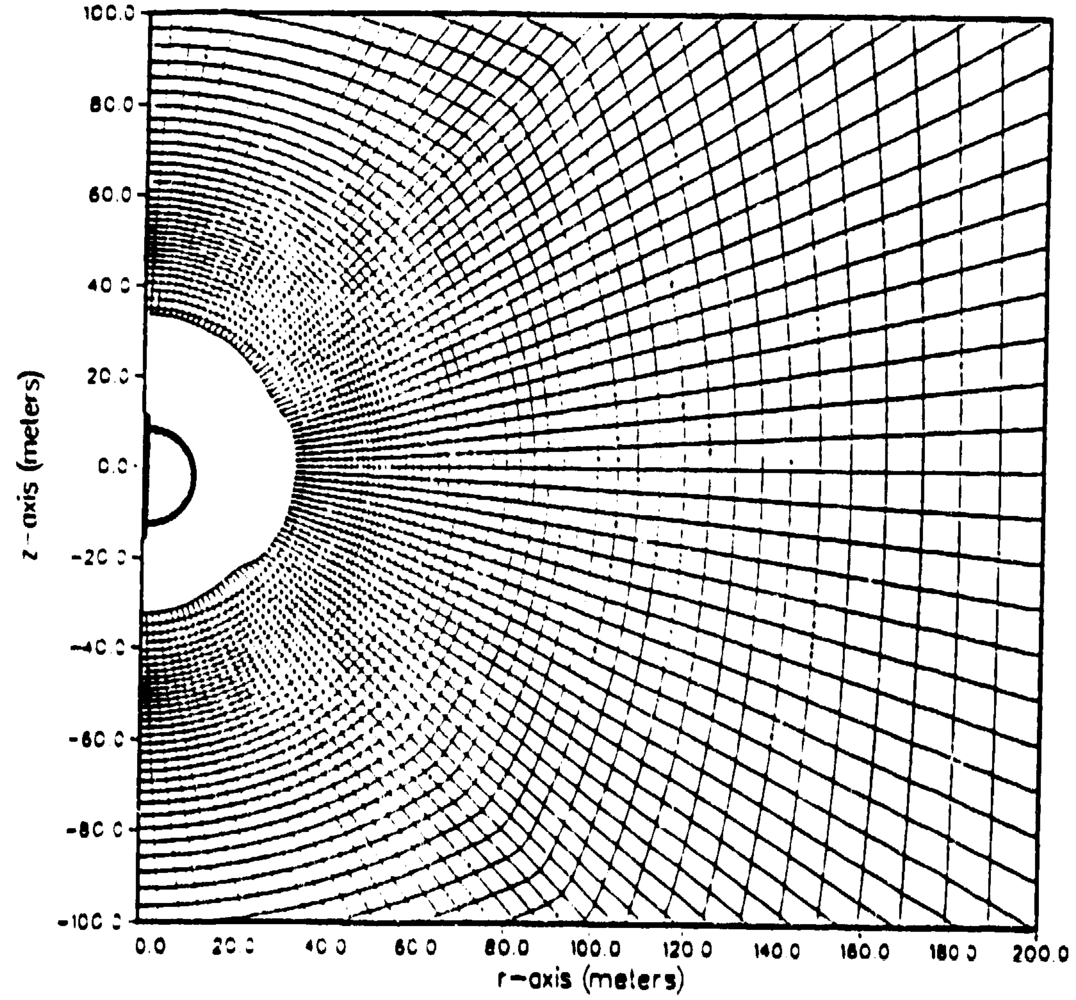

Fig. 2. The CRAM grid at the time the SOIL calculation is mapped over (9 msec.) and the initial cavity size used in the spherical source tamped 2D comparison calculation.

4. THE SEISMIC SIGNAL CALCULATIONS

The propagation of the hydrodynamic wave to the far field is carried out using the representation theorem. The displacements and stresses stored during the Lagrangian hydrodynamic calculating are used in the formula[11]

$$u_n(x,t) = \int_{\Sigma} [u_i(\xi,t) * c_{ijpq} v_j \partial_q G_{np}(x,t;\xi) - G_{np}(x,t;\xi) * v_i \sigma_{ip}(\xi,t)] d\Sigma \qquad (1)$$

to develop the displacements at teleseismic distances. $u_n(x,t)$ is at the observers position x in terms of spatial and temporal convolutions of the near-field displacements $u_i(\xi_i,t)$ and stresses $\sigma_{ip}(\xi_i,t)$ monitored at position ξ on the surface Σ with propagation Green's functions $G_{np}(x,t;\xi)$. The Green's functions are the displacement responses in the n direction at x due to point forces in the p direction at ξ . In Equation (1), v is the unit vector normal to the surface Σ and C_{ijpq} are the elastic coefficients. For the calculations presented in this report, the surface is a cylinder whose axis is vertical. The Green's functions, appropriate to teleseismic body waves, are calculated using the methods of Fuchs.[21]

5. CONCLUSIONS

The explosion simulations were saved on a cylindrical surface far enough removed from the source that the ground motions are linearly elastic. For the test of the methods we studied the explosion of a 150 kt source in the middle of a 32 meter radius cavity in granite. The results are compared with a one-dimensional (1D) calculation in Figure 3. An explosion in a scaled 6 $m/W^{1/3}$ radius cavity will show enhancement as observed. For the comparison to the asymmetric case we did a simulation for the tamped explosion using the CRAM code from the beginning (obs. Figure 2). This calculation utilized a better equation of state for the development of the cavity than the asymmetric case, but included the effects of the surface reflection in a nonlinear manner. A comparison of these results, in terms of body waves at various takeoff angles, is shown in Figure 4. Because of the differences in equations of state, the body waves from the tamped calculation are about 10 percent larger than the body waves from the asymmetric calculation, however they are very similar in shape and duration, and there is no apparent increase in variation as a function of takeoff angle due to the initial asymmetric source. There are two reasons for this. First, although the initial source is asymmetric, most of these effects damp out as the shock propagates through the nonlinear region, and second, the dominant frequency of the far-field body wave is low enough that it is insensitive to details of the explosion source.

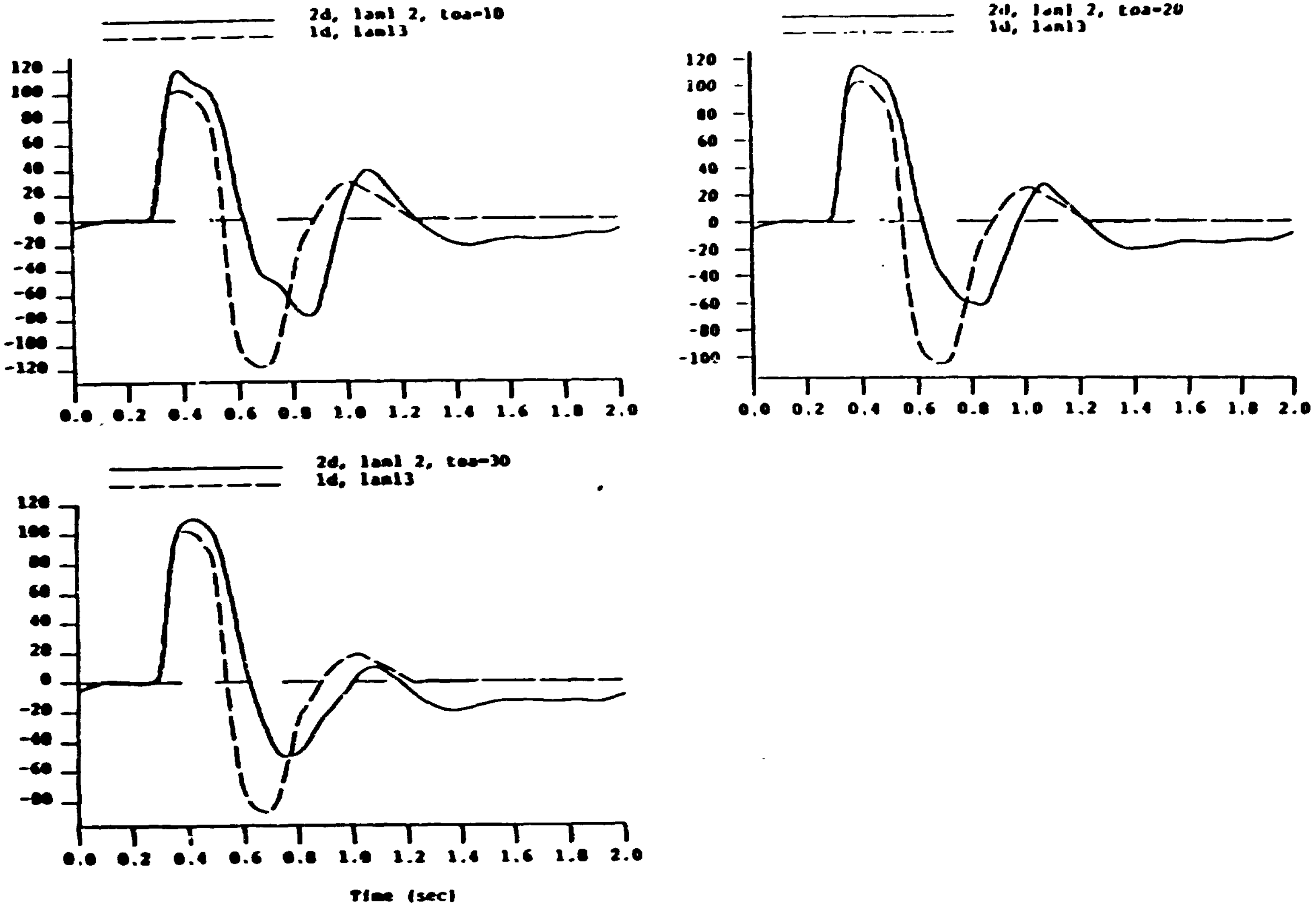

Fig. 3. A comparison of the far field seismic signals at various take-off angles as simulated for the 1D tamped case, with an elastic surface signal added, and to the 2D spherically symmetric 32 meter radius cavity case. note: the enhancement as observed is supported by one dimensional simulations.

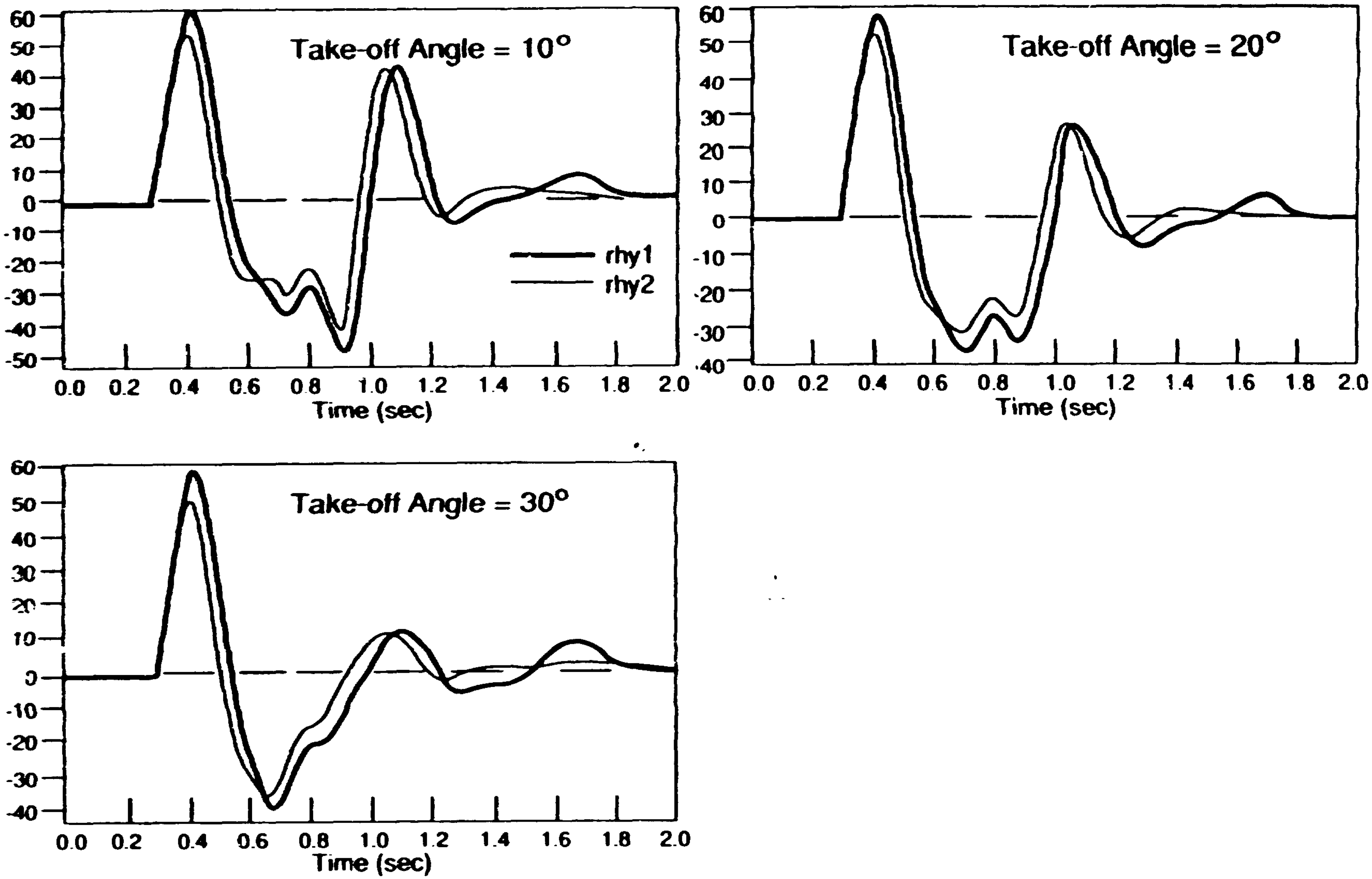

Fig. 4. A comparison of the far field seismic signals at various take-off angles from the tamped 2D calculation (heavy line) and the asymmetric 2D calculation (light line) as described in the text.

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