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Nonlinear Processes in Earthquakes

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Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at Los Alamos National Laboratory (LANL). Three-dimensional, elastic-wave-propagation calculations were performed to define the effects of near-source geologic structure on the degree to which seismic signals produced by earthquakes resemble "non-double-couple" sources. Signals from sources embedded in a subducting slab showed significant phase and amplitude differences compared with a "no-slab" case. Modifications to the LANL elastic-wave-propagation code enabled improved simulations of path effects on earthquake and explosion signals. These simulations demonstrate that near-source, shallow, low-velocity basins can introduce earthquake-like features into explosion signatures through conversion of compressive (*P*-wave) energy to shear (*S*- and *R*-wave) modes. Earthquake sources simulated to date do not show significant modifications.

Background and Research Objectives

The characterization of the seismic source mechanisms requires that account be taken of the effects of geologic structure along the propagation path. For example, although the seismic signals produced by many earthquakes are close to that predicted by simple source ("double couple") and path models, others are not. In some cases, the presence of non-double-couple components in the inferred seismic moment tensor may be due to the presence of a subducting slab in the immediate vicinity of the source. In other examples, signals observed from explosive sources show earthquake characteristics that are undoubtedly due to path effects. During the term of this LDRD project, we proposed to apply a three-dimensional elastic-wave-propagation code to problems such as those described here to study the extent to which seismic signals are modified by geologic structure.

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Importance to LANL's Science and Technology Base and National R&D Needs

As a signatory to the Comprehensive Test Ban Treaty (CTBT), the United States has a national need to detect and successfully characterize the seismic signals produced by clandestine, underground nuclear tests and to discriminate any such signals from the background population of earthquakes, quarry blasts, and mine explosions. In addition, application of the methodology to a wider range of problems provides both a testing ground for the codes and an opportunity to develop collaborations with university researchers.

Scientific Approach and Accomplishments

Los Alamos' 3-D elastic-wave-propagation code AFD [1] was applied to two problems in seismic source characterization. In the first case, models were constructed of an earthquake occurring near the upper boundary of a subducting slab such as might be found at the point of collision between a continental plate and an oceanic plate. It was expected that synthetic seismograms calculated at stations located at various ranges and azimuths would show significant deviations from those calculated without the slab being present. Code modifications were required for the definition of the subduction zone, and for more accurate treatment of boundary conditions.

Figures 1a and 1b show synthetic seismograms calculated at three stations with and without the subduction zone being present. Collaborators at the University of Texas had planned to use conventional, flat-layer analysis techniques to demonstrate that the inferred seismic moment tensor for the source would show non-double-couple components. Because of computer limitations, the synthetic seismograms calculated with AFD are recorded at locations relatively close to the source whereas conventional seismic analysis techniques require seismic signals from surface stations at large distances from the source. By midyear, it was realized that proper analysis of the numerical output would require the development, at Texas, of methods to utilize seismic histories at a large number of points near the outer boundaries of the numerical grid. The initial numerical results were used to generate a proposal to the National Science Foundation [2] for support of the analysis effort at Texas in FY 1997 and beyond.

The improved code was also applied to the problem of path effects on the seismic signals produced by explosions and earthquakes in Western China [3]. The improved code was used to do a parameter study in which the effects of various major geologic features

were isolated. These features include the low-velocity Tarim Basin southwest of Lop Nor and the deep depression in the crust/mantle interface (Moho discontinuity) that represents the root of the Himalayan range. As shown in Figures 2a and 2b, the low-velocity basin is particularly effective in converting compressive (*P*-wave) energy that is the main characteristic of an explosive source into shear wave (*S*-wave) energy that is characteristic of an earthquake. A paper describing these recent results is being prepared.

References

- [1] Kamm, J., Bos, R., and Jones, E., "User's Guide to AFD V.1.0," Los Alamos National Laboratory report LA-UR-96-853 (March 1996).
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- [3] App, F., Bos, R., and Kamm, J., "Synthetic Seismograms at Regional Distances for May 1995 Earthquake and Explosion Sources in Western China," Los Alamos National Laboratory report LA-UR-96-1600 (June 1996).

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Figure 1a. Three-component synthetic seismograms representing the diagonal (xx , yy , zz) components of the moment tensor, as observed at a history point 450 kilometers from a source at 50 kilometers depth in a subducting slab with a 10 percent velocity contrast. The dashed line is from the "no-slab" case. Z , R , and T correspond to vertical, radial, and tangential displacements. The slab dips down at 45 degrees in the direction of increasing x . The main phase groups visible are the direct P and pP group which arrives between 55 and 80 seconds, and the S , pS , sS group which begins arriving after about 100 seconds.

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Figure 1b. Off-diagonal (xy , xz , and yz) components for the slab (bold) and no-slab (dashed) cases. Note the change in vertical scale from Figure 1a. In both figures, differences in phase and amplitude between the slab and no-slab cases indicate that standard, flat-layer analysis techniques of the synthetic seismograms would produce inaccurate source characterizations.

Lop Nor to NIL

Figure 2a. Geologic structure along a path from the Chinese nuclear test site at Lop Nor (left) to a seismic station in northern Pakistan known as NIL (right). The major features of the cross-section are the low-velocity Tarim Basin which lies at ranges from Lop Nor between 100 and 1000 kilometers, and the deep Moho depression underneath the Himalayan Range at ranges from 1100 kilometers to the right side of the computational region.

Figure 2b. The upper portion of the figure shows a vertical-velocity seismogram at $x = 1100$ km for a case in which the Tarim Basin was not included. The first arrival from this explosive source is at about 140 seconds and is a compressive wave which travels mostly through the high-velocity mantle material. Arrivals starting at 190 seconds represent compressive energy ducted in the crust. The lower portion of the figure is a vertical-velocity seismogram at $x = 1100$ km for the case which includes the basin. The arrivals between 200 and 225 seconds represent compressive-to-shear (P - S) energy conversion at the upward sloping edge of the basin between $x = 600$ and 1000 km, and the arrivals between 340 and 360 seconds represent P - S conversions on the downward slope of the basin between $x = 100$ and 500. The large-amplitude arrivals after 400 seconds represent surface waves created in the basin. In a simple geologic setting, shear-wave arrivals would be characteristic of an earthquake source and not an explosive source.