Technology News

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IMPROVED IMAGING OF UNDERGROUND STRUCTURE: A NEW CURVED RAY TOMOGRAPHIC PROGRAM FROM THE BUREAU OF MINES

Objective

Develop a curved ray geotomographic program with constraints to counteract non-uniqueness in order to improve the reliability of seismic tomographic imaging of geological structure in mining regions.

Background

Seismic tomography provides a two-dimensional image (tomographic reconstruction) of the distribution of the seismic velocity in geologic structures using measured travel times of seismic waves crossing the area. It can provide a more complete representation of features between boreholes than other crosshole processing methods that measure only average properties or borehole logging methods that measure properties only near each borehole. Seismic tomography has many mining applications. They include locating geologic structures of contrasting seismic velocity, detecting fractured regions where the seismic velocity is low, and monitoring solution injected above the water table where the increase in saturation increases the seismic velocity. Thus, tomographic imaging techniques show great promise for detecting and locating geologic hazards that affect the productivity, safety, and environment of mining operations.

The Problem

To provide reliable imaging in regions of highly variable seismic velocity, the tomography program must provide curved ray tracing to take into account the bending of the seismic waves as they move between zones of contrasting velocity. The program must run successfully with data from regions of highly variable seismic velocity. Mathematical methods that are adequate when the bending is small may fail because of numerical instability or excessive running time when the bending becomes larger.

To provide reliable imaging with crosshole data, the tomographic analysis program must provide optional mathematical constraints to counteract the non-uniqueness of the tomographic reconstructions. Tomographic analysis of crosshole data without constraints does not yield a unique reconstruction; many distributions of the velocity would fit the data equally well. Commercial programs did not provide the combination of curved ray tracing and the desired constraints, and did not provide a source code to allow Bureau of Mines' researchers to add the constraints. Public domain programs for which the source code was available failed when applied to regions with highly variable seismic velocity.

Approach

The U.S. Bureau of Mines developed the tomographic computer program BOMCRATR (Bureau of Mines Curved Ray Tomographic Reconstruction) with constraints to help obtain unique reconstructions. It uses mathematical techniques that allow the program to run successfully with data from regions of highly variable seismic velocity. BOMCRATR provides the following features:

1. The ability to perform either curved or straight ray analysis, which is useful for determining when the slower, curved ray analysis is necessary.
2. The ability to test the uniqueness of reconstructions.
3. Constraints to help counteract the non-uniqueness of tomographic reconstructions.
4. Interactive setting of control parameters, such as the number of iterations and constraints.
5. The ability to skew the grid to deal efficiently with slanted or crooked boreholes.

Program Tests and Constraints

BOMCRATR allows the user to test uniqueness by varying the initial velocity guess used to start the iterative solution procedure. A unique reconstruction is independent of the initial velocity guess. A combination of unrealistically long paths and unrealistically high velocities could fit measured data, so allowable ray paths must remain within the grid region. BOMCRATR provides the following optional constraints:

1. Minimum and maximum calculated velocities.
2. Known, fixed velocities in boreholes, such as from sonic logs.
3. Fixing the velocity to the initial value at any point or combination of points.
4. Horizontal layers near the top and/or bottom of the investigated area in which seismic velocity does not vary with horizontal position.
5. Smoothing, in which the calculated velocity at a node is influenced by the velocities at neighboring nodes.

For More Information

U.S. Bureau of Mines Report of Investigations (RI) 9411, by D.R. Tweeton, M. J. Jackson, and K. S. Roessler, describes BOMCRATR and gives results with synthetic and field data. A free copy of the report may be obtained by writing to the Bureau's Publication Distribution Section, P.O. Box 18070, Cochrans Mill Road, Pittsburgh, PA 15236.

Applications to the evaluation of blast damage and in situ mining are described in the Proceedings of the Tenth WVU International Mining Electrotechnology Conference, sponsored by West Virginia University, July 24-27, 1990, and in Geoexploration, v. 28 (1991) pp. 251-268. A limited number of reprints of the latter publication are available from the authors.

Source and executable codes in FORTRAN on IBM-compatible diskettes are available from the authors at U.S. Bureau of Mines, Twin Cities Research Center, 5629 Minnehaha Avenue South, Minneapolis, MN 55417-3099 (612/725-4670).

BOMCRATR Features:

- Curved or straight ray tracing.
- Test of uniqueness of reconstructions.
- Constraints to counteract non-uniqueness.
- Interactive setting of options.
- Flexible grid pattern.