Abstract

The fundamental concept in tomographic imaging is that of the projection. Energy is radiated through the object being studied; it interacts with the material, and is received and measured after passing through it. Spatial variations in the physical properties of the interior result in corresponding variations in the characteristics of the energy received; in other words, the measurements constitute a projection of the internal structure. Thus, seismic imaging produces the raster image of the internal structure by combining information from a set of projections obtained at different viewing angles. Electrical resistivity tomography (ERT), on the other hand, is a method for determining the electrical resistivity distribution in a volume from discrete measurements of current and voltage made within the volume or on its surface.

Raniganj Coalfield is one of the largest coalfield in India exploited continuously for over 200 years. The coal workings suffered numerous cave-ins, inundation and even mine fires, because of lack of adequate safety measures in areas peppered with unknown, unstable and abandoned colliery workings. The full sequence of the Raniganj Formation covers 10 regionally correlatable coal-seams having the nomenclature R-I to R-X, with local names. The three test sites North Searsole, Bansra and Dhandadih collieries are located in the centre of the Raniganj Coalfield some 200km northwest of Calcutta. The working coal seams of these three sites are Kenda bottom (R-V), Purandip bottom (R-VII) and Jambad top (R-VIII) respectively. North Searsole and Bansra have dry and approachable underground workings while Dhandadih is waterlogged and uncharted.

Shear-wave Seismic Tomography (SWST) data are recorded with the help of a shear-wave-generating hammer system (downhole source), a 3-component geophone (downhole receiver) with a natural frequency of 40 Hz and a 24-channel BISON seismograph. In the case of surface-to-borehole configuration, the surface source is a 5kg sledge hammer struck on a steel plate. The sample interval was set at 0.1 ms for the broad frequency band of 30-250 Hz. For crosswell geometry, sources and receivers are placed in two different boreholes at depths depending upon the respective target coal seam depth. For surface-to-borehole geometry, both the surface shots and borehole receivers are placed at 4m interval.

The equipment used for the electrical resistivity tomographic survey is a Scientrex PC-7-50 transmitting unit with a 2.5 KVA generator and a Scientrex RDC-8 receiver. The current electrodes are galvanized iron (on-surface) and copper bars (in-hole). Potential electrodes on-surface along a line consisted of porous pots with the copper electrode in contact with the copper sulphate solution. For crosswell surveys, potential electrodes combined two spring-loaded copper electrodes in good contact with the borehole wall. A pole-dipole array is used. For the surface-downhole configuration, the potential electrodes are separated by 3m and the measurement are taken at every metre.

In the Raniganj Coalfield about 42 areas have been identified requiring stabilization. Some surface geophysical methods have already been applied for locating the underground workings, but most of them have failed due to the geophysical constraints posed by the surface weathered layer. Shear wave seismic and Electrical resistivity tomography - the two sophisticated subsurface geophysical tools are applied here for the purpose. Our tomographic applications centre around these test sites for the detection of mining hazards.

The present investigation attempts the followings:

- Shear-wave seismic and resistivity tomographic data acquisition at Raniganj Coalfield.
- A configurative resolution test performed to establish the necessity of a combined interpretation of the three source-receiver configurations in seismic transmission tomography.
- The algorithms based on Simultaneous Iterative Reconstruction Technique (SIRT) and Simulated Evolution (both GA and EP) developed for seismic transmission tomography in 2D and tested on a variety of numerical models and the real field settings at the Raniganj Coalfield, West Bengal, India.
- A 3D seismic transmission tomographic interpretation of the colliery data.
- 2D electrical resistivity tomography using Genetic Algorithm; validation through numerical examples and applications in the detection of mining hazards (voids / galleries in the coal seam).
- 3D resistivity tomography using Conjugate Gradient method and development of the quasi-3D subsurface models for the identification of galleries in the coal seams in the Raniganj Coalfield.
- Comparison and combined analysis of the seismic and ERT raster images for the minimization of inherent ambiguity and hence enhanced resolution of the detected abandoned galleries in the coal seams.

The tomographic interpretation methods namely SIRT, ART and CGT are calculus-based enumerative techniques wherein the subsurface region between the boreholes is decomposed into a number of tiny constant velocity cells. The inversion is actually performed on the time derivative matrix. But these methods fail to resolve discontinuities in the velocity/slowness distribution most of the times.

Conventional ray-tracing techniques and inversion algorithms encounter many difficulties when applied to tomographic analysis, for example.

i) head waves are not generally included,

ii) a single raypath is usually assumed for each source-receiver pair,

iii) large computation time is required for many source-receiver pairs,

and iv) it is difficult to find a raypath in a complicated velocity distribution.

To overcome these problems a ray-tracing algorithm is used based on the reciprocity principle and dynamic programming approach. This robust forward calculation routine is used in the implementation of seismic transmission tomographic applications in the present investigation.

Since the optimal solution starting with even poor initial models is aimed at, the global optimization and search techniques like simulated evolution, can be applied in the implementation of our tomographic formulation. Compared to traditional methods such as analytical and enumerative strategies, the simulated evolution is robust, global and generally more straight forward to apply. Natural evolution is a population-based optimization process. Simulating this process on a computer results in the stochastic optimization techniques that can often outperform classical methods of optimization when applied to difficult real-world problems like imaging the complex subsurface structure of the earth. Genetic algorithms, evolution strategies and evolutionary programming are the main avenues of research in the simulated evolution. Genetic algorithms stress chromosomal operators. Evolution strategies emphasize behavioral changes at the level of the individual while evolutionary programming stresses behavioral changes at the level of the species. In the present work both GA and EP schemes are implemented to tackle the tomographic solutions in both seismic and resistivity imaging of the subsurface. A new genetic operator called *'Region-growing mutation'* is used to speed up the search process.

The 3D seismic tomography software is downloaded from the Public domain of US Bureau of Mines and it works on the principles of Network theory and Ray Bending while the inversion is done using SIRT. A quasi-3D velocity image is developed from the 2D sections evolved from GA algorithm and interpolation by Kriging for better representation of the subsurface model in 3D.

In the recent past, substantial advancement have been made in the numerical modelling of the electrical response of geological structures. Recently, Zhang et al.

(1995) have introduced a rapid resistivity forward modelling and inversion algorithm based on conjugate gradient in 3D. We used this software for the ERT imaging of the subsurface lithostratigraphy.

The Genetic Algorithm routine used in seismic tomography is modified and adopted for the electrical resistivity tomographic reconstruction in 2D and we referred to it as ERTGA in this thesis. For ERTGA algorithm the forward problem is solved by Zhang's algorithm of conjugate gradient.

All the algorithms viz., 2D SIRT, 3D SIRT, 2D GA in Seismic and 3D ERT and 2D ERTGA in geoelectrics are rigorously tested on numerical models for judging their efficacy.

Since we aimed at analyzing and interpreting the colliery data, an attempt is made to apply the above proposed algorithms in solving environmental, geotechnical and civil engineering problems from shear wave seismic tomography (SWST) and electrical resistivity tomography (ERT) data. The residual traveltime and transfer resistance surfaces are generated as raster images to analyze the quality of the data recorded in the field. In these raster displays each pixel corresponds to one source-receiver pair. This way the residual traveltime and transfer resistance surfaces are generated for all the collieries for different crosshole combination. All the colliery data are tested for their quality, preliminary 1D model generation, seismo-electric model generation and the construction of final velocity and resistivity raster images depicting the coal seams with or without voids in those. The velocity and the resistivity bounds are discretely coded in 8-bit using 0-255 integer codes. Proper book keeping is done to store the real values pointing to a code in the memory while executing the programs. The model region in 2D and 3D are discretized into finer mesh and the raster images in most of the cases are displayed in 512 × 512 pixels.

The tomograms and the stacked 3D images reconstructed by 2D SIRT, 3D SIRT, 2D GA, 3D ERT and 2D ERTGA algorithms show the lateral shear / *P*-wave velocity and resistivity variations at different depths at North Searsole, Bansra and Dhandadih collieries. While seismic tomography could depict the dry voids in the coal seam at North Searsole and Bansra, the resistivity tomography failed due to infinitesimal resistivity contrast between the void and the coal seam bed. At Dhandadih, however, the galleries being water logged, both seismic and resistivity tomography could image the voids successfully. Generally, in all the cases, the coal seams are better delineated by electrical resistivity tomography than the seismic tomography. Therefore, using the appropriate measurement and processing tools under favourable circumstances both the seismic transmission and electrical resistivity tomography are the viable and powerful methods for solving shallow subsurface exploration and monitoring problems. The present investigation is an attempt in that direction.

KEYWORDS

2D SIRT, 3D SIRT, 3D electrical resistivity tomography (3D ERT), Acoustic reciprocity principle, alpha centers, analytical method, ART, back projection, Bansra, BISON Seismograph, borehole geophone, borehole hammer system, borehole current electrode, borehole potential electrode, borehole-to-surface (reverse VSP), boundary or volume integral method, buffer zone, CDI, CGT, Combined interpretation, Conjugate gradient relaxation method, convergence, crosshole, crossover, current electrode, Dey and Morrison's mixed boundary condition, Dhandadih Colliery, diffraction tomography, dipole-dipole arrays, dipole-pole, dynamic programming approach, electrical resistivity tomography (ERT), electromagnetic tomography, evolutionary programming, evolution strategies, Fermat's principle, Filtered back projection, finite difference method, finite element method, fitness function, Forward modeling, Fourier transform, gallery, Gaussian distribution, genetic algorithm, global optimization, Gray coding, homogeneous Neumann's boundary condition, horizontal resistivity model horizontal velocity model, hybrid approach, hybrid ray-tracing, incomplete Cholessky preconditioning, iterative reconstruction, Jambad Top, Kenda Bottom, Kenda Top, Kriging interpolation, matrix inversion, maximum likelihood inversion, Medical tomography, mining hazards, mutation, network theory, North Searsole, Occam's inversion, pillar, potential electrode, pole-dipole, pole-pole, population, Purandip, quasi-2D resistivity section, quasi-2D velocity section, quasi-3D simulation, Raniganj Coalfied, ray-bending, raypath, RAYPT, ray stereoplots, ray-tracing, reflection, refraction, region-growing mutation, residual transfer resistance surface, residual traveltime surface, root bisection method, sand stawing, Scientrex transmitter & receiver, sensitivity matrix, shear wave seismic tomography (SWST), simulated evolution, SIRT, slowness/velocity matrix, Surface-to-borehole (VSP), time-distance plot, transfer resistance, transmission, traveltime tomography, traveltime vector, velocity histogram, voxel.