

P060 HIGH RESOLUTION GPR AND SEISMIC INVESTIGATIONS – INTERPRETATION THROUGH MODELLING

G. W. TUCKWELL¹ AND N. J. CASSIDY²

¹STATS Geophysical, Porterswood House, St Albans, AL3 6PQ, UK

²Keele University, UK

Summary

The application of geophysical techniques in which energy is transmitted through the subsurface as waves is widespread, and the applications of such techniques are numerous. Here we consider two such techniques, Ground Penetrating Radar (GPR), and seismic refraction. Both of these techniques rely on the modification of the transmitted energy by variations in physical properties within the subsurface, and the subsequent transmission of a portion of this energy to receivers at the surface. The interpretation of such data relies on the experience of the practitioner, and to a lesser extent, the expectations of simple conceptual models, for example the assumption of lateral homogeneity or smooth surfaces between material types.

In the majority of current applications of GPR and seismic refraction, an experienced user can extract all of the desired information by careful processing of the data. However, in cases where subsurface geometry is unknown, or important subsurface variations occur at a length-scale approaching the resolution of the technique, realistic numerical modelling of receiver responses can prove to be a valuable interpretive tool.

We describe two separate numerical modelling schemes based on a finite difference scheme, and a discrete element scheme, designed to accurately model the full subsurface wave fields of electromagnetic and seismic energy respectively. The advances represented by these new software applications offer exciting new opportunities not only for the interpretation of geophysical data, but also for the effective planning of GPR and seismic surveys and the greater applicability of these techniques to more complex and challenging survey goals.

Discrete Element Modelling of Seismic Waves

This methodology has a number of advantages over traditional “grid-based” finite difference schemes, or other methods such as finite or boundary element. In summary the key advances are:

- An accurate description of the free surface.
- No constraint on the geometry of material boundaries, or on the contrast in material properties.
- Accurate simulation of fractures, delaminated layers, and disaggregated material.
- 2D and 3D formulation.

The distinct element method simulates the behaviour of elastic particles that interact at point contacts under the effect of specified force or displacement boundary conditions. In our implementation, interactions between spherical particles (in 3D) or discs (in 2D) are controlled by an elastic stiffness parameter associated with each particle, and, in the case of non-bonded particles, by a Coulomb friction law applied at particle-particle interfaces. An explicit finite difference algorithm simultaneously solves the equations of motion and the force-displacement law to calculate, respectively, the particle positions in space and the dynamic forces acting at each contact. To ensure numerical stability, a time step, which depends on ball stiffness and density, is calculated for each particle in the model and a critical time step is chosen such that a mechanical disturbance cannot propagate further from any particle than its immediate neighbours during each calculation cycle. The particles can be bonded together at point contacts to simulate the behaviour of a cohesive rock.

Particle stiffness and the geometric arrangement of particles is known to influence the Young's modulus and Poisson's ratio (e.g., Hoover et al., 1974). Thus, the macroscopic behaviour of materials is controlled by the microparameters assigned to individual particles.

Finite Difference Modelling of EM Waves

The propagating electromagnetic GPR waves are modelled by a three-dimensional, staggered, orthogonal, fourth-order, finite-difference time-domain (FDTD) numerical approximation to Maxwell's electromagnetic field equations. The scheme includes:

- A wide range of materials with anisotropic, frequency dependent permittivity, conductivity and, where necessary, magnetic permeability.
- Three-dimensional target features and complex sub-surface geometries.
- Realistic antenna designs including shields, signal damping and accurate source signal forms.
- 'Memory variables' to determine the time, and therefore frequency, dependant effect of the materials on the propagating EM wave.

The current scheme was developed by Cassidy (2001) and is total-field, explicit, robust and provides accurate models of velocity and dispersion without the need for fine spatial sampling. Having simple criteria for determining the conditional stability limits, error bounds and accuracy, the technique is based on a three-dimensional orthogonal, Cartesian, computational grid system compatible with the commonly used 'Yee' cell geometry (Yee, 1966). The computational domain is divided into individual cells; each containing three orthogonal electric field vectors (E_x , E_y , E_z) staggered in space with three orthogonal magnetic field vectors (H_x , H_y , H_z). The field equations are sequential in time so that each update cycle calculates the total magnetic field, the memory variables and then the total electric field.

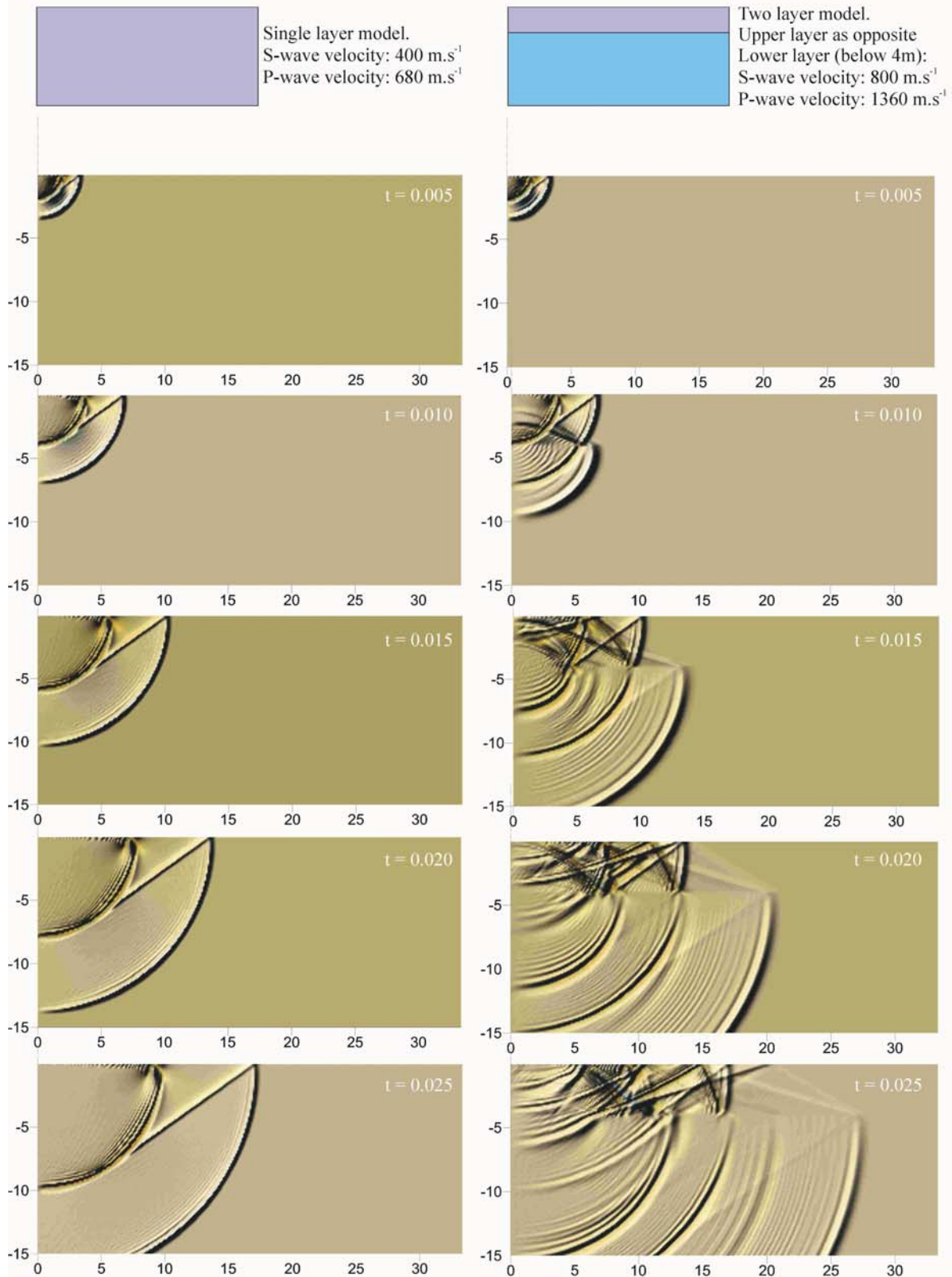
Each sub-surface material is described by a complex permittivity, conductivity and magnetic permeability spectrum (Cassidy 2002) and although the effect of the permeability is often negligible it must be included when iron-oxide rich materials are present. The permittivity spectrum is described by a superposition of individual electric field and electric flux density relaxation times (τ_e and τ_d), combined with a static permittivity (ϵ_s). The complex conductivity is described by a static conductivity (σ_s) and a conductivity relaxation time (τ_σ). These parameters can be obtained directly from the sub-surface materials by the dielectric measurement and inversion or from theoretical/empirical models.

The transmitting and receiving antennas are described by half-wave, centrally fed, resistively loaded dipoles with a double PEC (perfect electric conductor) 'metal shield' being used to model the antenna enclosure. The source wavelet is an accurate representation of the true GPR pulse (Cassidy 2001), and is based on the recorded signal in air. Developed from the standard Ricker pulse, it is smooth and continuous in both its first and second derivatives and can be optimised to suit the central frequency of any antenna.

References

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- Hoover, W. G., Ashurst, W. T., & Olness, R. J., 1974. Two-dimensional computer studies of crystal stability and fluid viscosity, *J. Chem. Phys.*, 60, 4043-4047.
- Yee, K.S., 1966. Numerical solution of initial boundary value problems involving Maxwell's equation in isotropic media. *IEEE Trans. Antennas and Propagation*, Vol. 14, No. 2, pp. 302-307.
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Discrete element models of a simple seismic refraction experiment

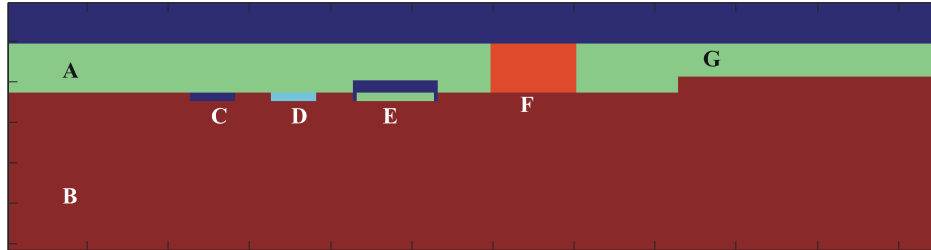


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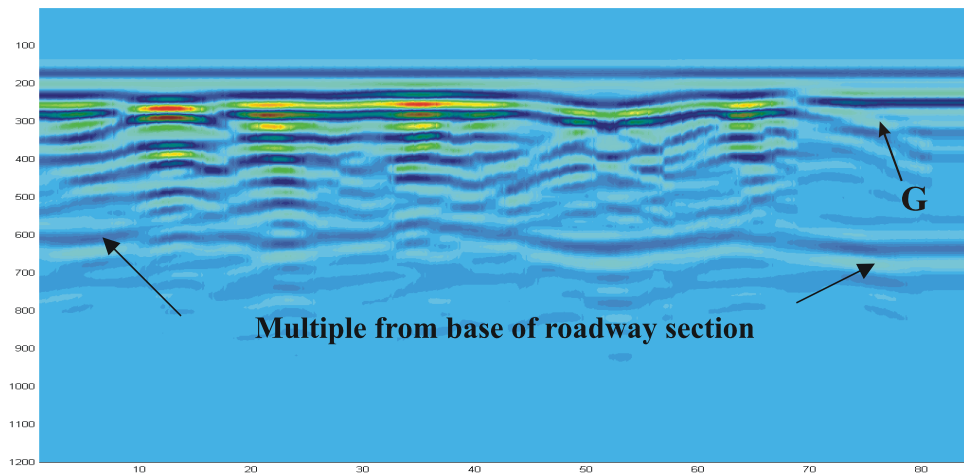
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900MHz GPR Model – Sub-surface model

Concrete roadway (A) sand/aggregate substrate (B) air filled void (C) mud filled void (D) fractured and separated concrete section (E) fractured/salt corroded zone (F) and a reduction in concrete depth (G).



Reflection from base of Concrete roadway (A) air filled void diffraction (C) mud filled void diffraction (D) fractured and separated concrete section reflection (E) fractured/salt corroded zone velocity pull down and 'bow tie' (F) and reflection from reduction in concrete depth (G).



(G) The reflection from the base of the thinner section of concrete actually looks as if it is as DEEP as the main roadway reflection, even though it is not. This results from the superposition effect of the ground and reflected GPR waves

