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Multiparameter Numerical Medium for Seismic Modeling, Planning, Imaging & Interpretation Worldwide

Tesseral 2.5D-3C - a 3D-3C full-wave modeling for complexly built elastic, anisotropic, thin-layered 2.5D medium model

Preamble

***Tesseral* Technologies Inc.** has established itself as a provider of the state-of-the-art 2D full-wave seismic modeling through its software package, ***Tesseral* 2D** Full-wave modeling package. However, since the industry is predominantly using 3D seismic observation and processing, many of our clients desire to have ability to model 3D observations. Presently, full 3D elastic modeling requires (not to mention viscoelastic) enormous computational resources (the paper on the EAGE 2006 have described a 3D modeling effort for relatively small model when one shot for the 3D full elastic model was calculated for more than a month on a cluster with several thousand processors). Necessary for this computational power is still out of scope for the great majority of our users. That is why in Tesseral package we have now introduced a new functionality for 3D (three-dimensional) 3C (three-component Vz, Vx, Vy) modeling with 2.5D medium framework. It is oriented on now widely spread medium-range clusters.

What is 2.5D-3C modeling and why is it important

2.5D-3C full wave modeling allows the user to build a realistic 3-D model including:

- ✓ Abilities to define a true elastic model.
- ✓ Take into account thin-layering effects (such as quasi-anisotropy, frequency dependent velocity of wave propagation and dispersion).
- ✓ TTI anisotropy of the media.
- ✓ Fractured media.
- ✓ Ability to create multi-component 3D-3C (3-dimensional and 3-component survey) and 3D-9C (including directional source) shotgathers for both CDP and VSP observations.

2.5D-3C modeling (unlike “full” 3D modeling) requires certain simplification of the medium model. The parameters of the media are assumed to be constant along the OY-axis. However the symmetry axis of all the anisotropy parameters (including the anisotropy that is caused by fracturing) can be of any spatial orientation.

Unlike in 2D modeling, the waves can propagate not only in XZ planes but in all three dimensions – to put it simply, the forward modeling is a true 3D, but the media in the model is simplified. For the case of the TTI anisotropy (or tilted fracturing, or its combination), 2.5D-3C modeling allows to simulate both “fast” and “slow” shear waves and takes into account all of their qualities such as wave coupled refraction. The proposed method would take into account Q (the absorption property of seismic energy by the media are re-calculated into “complex” parameters in correspondence of the parameters of the Q-factor for P- and S- waves), and will allow to accurately simulate polarization effects for both surface waves and volume waves for all three components of wave field.

The properties of the media along the XZ plane can be of any complexity. Due to this, 2.5D-3C model will provide the correct 3D results for locally stretched (up to tens of kilometers) very complex models, such as the ones in tectonically new areas, with developed folding, which are known for their complexity.

For a great number of models approximating 3D medium, the results of the 2.5D-C will provide virtually the same results as the “full” 3-D wave equation modeling (regardless of their complexity along XZ plane). This kind of modeling can be successfully used for creation of 3D-3C (3D-9C) datasets for testing of processing algorithms, survey planning and 3D-3C data interpretation in order to locate the fractured zones (by using azimuthal AVO method), doing full elastic inversions, etc.

Wave propagation equations

Wave propagation equations in terms of elastic deformation of the anisotropic medium, in general case may be denoted as follows (by repeating indexes summation is executed):

$$\rho(\vec{x})\frac{\partial u_i(\vec{x},t)}{\partial t}=\frac{\partial \tau_{ij}(\vec{x},t)}{\partial x_j}+f_i(\vec{x},t) \tag{1}$$

$$\frac{\partial \tau_{ij}}{\partial t}=\lambda_{ijpq}(\vec{x})\frac{\partial u_p(\vec{x},t)}{\partial x_q}+\frac{\partial M_{ij}(\vec{x},t)}{\partial t}, \tag{2}$$

where $\vec{x}=(x_1,x_2,x_3)$, u_i - components of the displacement vector, τ_{ij} - components of stresses tensor, ρ - density, λ_{ijpq} - components of elasticity tensor, f_i - components of external forces, M_{ij} - components of coupled forces (dipoles).

Let denote $\vec{r}=(x_1,x_3)$, k_2 - as spatial frequency by x_2 coordinate and present components of the displacement velocity vector and the stresses tensor in Fourier-domain accordingly to formulae:

$$g(\vec{x},t)=\int_{-\infty}^{\infty} g(\vec{r},k_2,t)e^{jk_2x_2}dx_2 \,. \tag{3}$$

In formulae (3) expression $g(\vec{x},t)$ denotes one of the displacement velocities vector component and the stresses vector in a domain $(\vec{x},t)$, and $g(\vec{r},k_2,t)$ determines values of the same component in a domain $(\vec{r},k_2,t)$.

Functions $g(\vec{r},k_2,t)\in\mathbf{C}$ are denoted in abbreviated form as $g\equiv g(\vec{r},k_2,t)$.

In 2.5D-3C is assumed that the medium properties ρ and λ_{ijpq} do not change along x_2 direction.

That is why to equations (1), (2) can be applied Fourier-transform by x_2 variable.

As result is obtained the equations system:

$$\rho\frac{\partial u_i}{\partial t}=\frac{\partial \tau_{im}}{\partial x_m}+jk_2\tau_{i2}+f_i, \tag{4}$$

$$\frac{\partial \tau_{ij}}{\partial t}=\lambda_{ijpm}\frac{\partial u_p}{\partial x_m}+jk_2\lambda_{ijp2}u_p+\frac{\partial M_{ij}}{\partial t}, \tag{5}$$

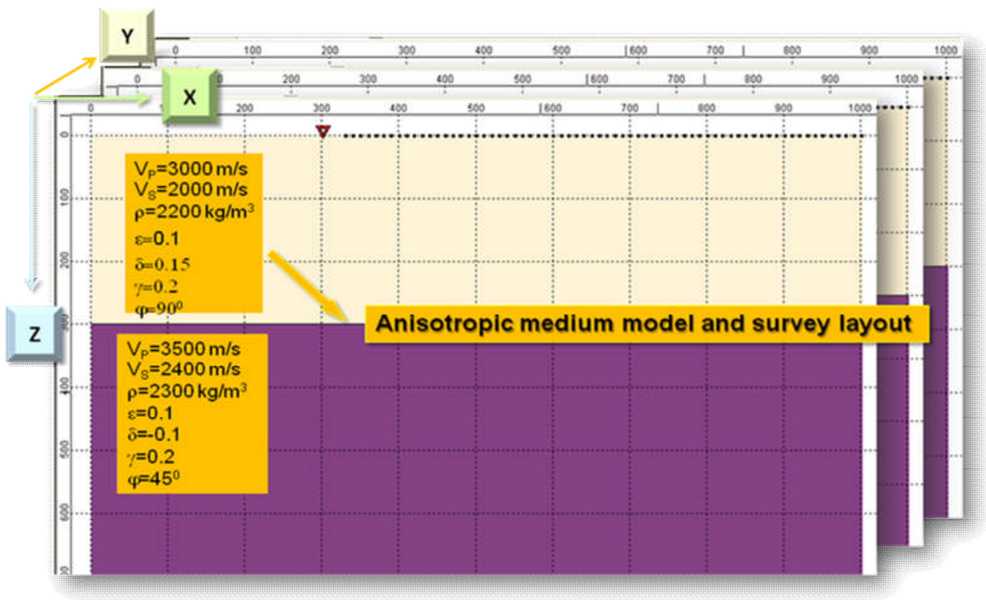
where m takes values 1 and 3, $j=\sqrt{-1}$.

Program Implementation and Hardware Requirements

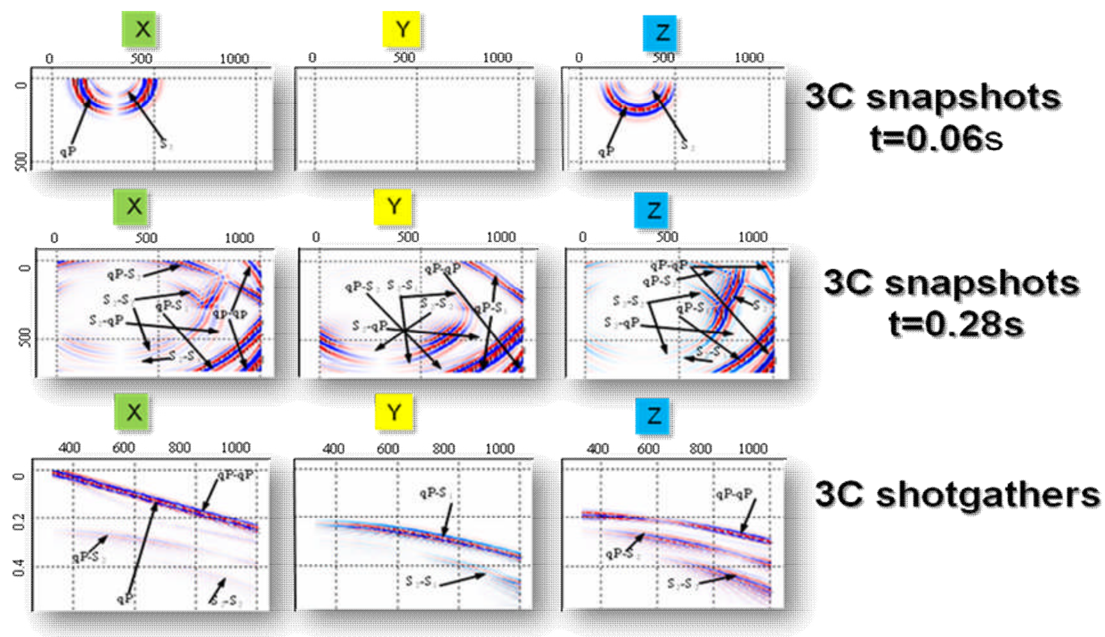
2.5D-3C modeling is realized on Linux cluster. 2.5D-3C computations algorithm allows effective parallelization on cluster with minimal exchanges of information between cluster nodes. In average time of computation of 3D CDP shotgather using this 2.5D-3C method on cluster with 100 nodes will be approximately the same as modeling in Tesseral 2D in XZ-plane only using one node.

Example

Below is shown two-layered HTI-anisotropic medium with azimuths of symmetry axis 90^0 and 45^0 correspondingly relating to line Y=0.



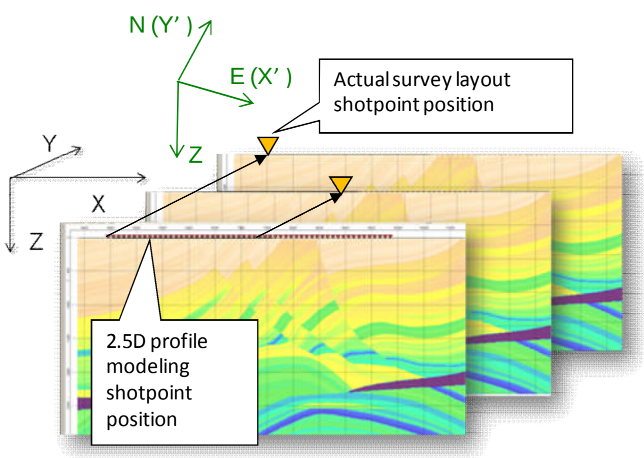
In next figure are shown areal 3C snapshots and shotgathers, containing X, Y, and Z-components for given medium model.

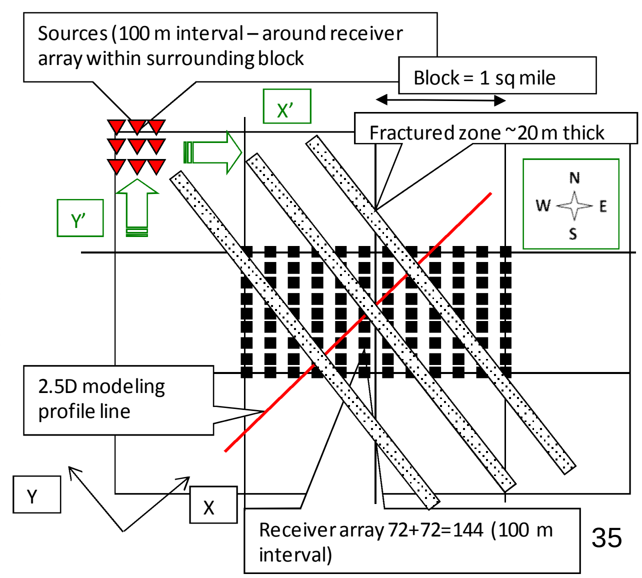


From given figure it can be seen that in the medium are propagating waves: qP, qSV(S_2) and SH(S_1). Arrival time of reflected converted PS_1-wave is earlier, than reflected converted PS_2-wave.

Orienting of 2.5D-3C modeling profile transversely geological strike for any 3D (3D-3C) seismic survey layout orientation

- In case of considerable difference in azimuths between geological strike and survey lines can be used more dense positioning of shotpoints and receivers along X- (2.5D profile orientation) and Y- (2.5D broadside offsets) axes for modeling of 3D (3D-3C) survey.
- Then for each of actual shotpoint and receiver locations on the 3D survey can be determined closest shotpoints and receivers positions from the 2.5D profile and corresponding broadside offsets.
- By both replicating of 2.5D profile synthetic data and doing linear coordinate transformation along with some regular form of trace selection, may be achieved required likeness with particular 3D (3D-3C) survey arbitrary oriented towards main geological strike. This allows bypassing of 3D finite-difference modeling computations, which still are unproductively huge for elastic (elastic anisotropic) approximations of wave equation, and applying of this modeling technique to industry scale modeling tasks in 3D seismic prospecting and 3D-3C data interpretation.





Conclusions

- ✓ 2.5D-3C modeling allows simulating 3D-3C (3D-9C) seismic observations without retorting to very expensive hardware (supercomputers) and very long computational run. 2.5D-3C modeling is a relatively inexpensive and quick way to obtain a good approximation to 3D conditions. This program can be useful for processing, data interpretation, for planning of surface and well surveys etc.
- ✓ 2.5D-3C modeling can work on relatively affordable hardware (as opposed to full 3D modeling) and will provide the modeling results that – in most of the cases – would be no different from the results of full 3D elastic anisotropic modeling.