Abstract

When using local velocity scans for layer stripping during model building in 3D Kirchhoff Pre-SDM, the velocity that allows the best flattening of seismic events on image gathers can be considered as correct for updating the velocity field. Its implementation is extremely tedious in practice, as it requires computation of Green’s functions for all scanned velocities. However, some practical implementations provide efficient ways for reconstructing the required traveltimes with a high degree of accuracy. Two approaches are possible: (1) compute Green's function and its first derivative to extrapolate the desired traveltimes, (2) use a hyperbolic interpolation between two traveltime solutions obtained at each extremum of the set of scanned parameters. The first method is only suitable in the isotropic case. The second method is more efficient, and also applicable in the anisotropic case. The anisotropic parameters scanned by the latter approach are either Thomsen's parameters (\(\varepsilon\) and \(\delta\)) or the quasi-anisotropic compaction coefficient \(K\). Experience has shown that the first reconstruction technique can extrapolate accurately to within a 15% range of velocity, while the second technique can handle a range of 40% for \(V\) and \(K\), and 20% for the anisotropic parameters.

Introduction

The natural tool for velocity model building in 3D Kirchhoff pre-SDM is the production and display of the output gathers sorted by offset or reflection angle collections, in common migrated positions. But the shape of the residual moveout from a seismic event corresponding to the base of a given velocity layer can be relatively complicated as it not only depends on its propagation velocity but also on the geometry of the upper interface. The appropriate solution for handling the observed information in this kind of situation consists in solving the problem with a tomographic technique from an automated picking of the seismic events on the image gathers (Guillaume et al., 2001).

The use of local velocity scans appears as an alternative to this kind of solution, especially when the picking is difficult because of a poor signal-to-noise ratio. Among the set of scaling factors applied to the velocity field, the one which best flattens the seismic events on the image gathers may be considered the right one to be used for the velocity field update. This update may affect one single value for the velocity inside the considered layer. It may also be local, and several scaling factors may be applied vertically just above the velocity analysis position. A more sophisticated technology can also be applied by translating the picking of the optimal scaling factors from depth to time by a tomographic inversion.
In reality, many model parameters can be scanned: one could be the velocity as a single parameter, when dealing with a homogeneous salt body, for example. In fact, and this is a very important point, the efficiency of the scans will be enhanced if the presumed parameterization used to describe the vertical and lateral velocity variations fits the actual behavior of the specific layer under investigation.

If the isotropic velocity field is related to a single layer and parameterized as a 2D grid of values Vo(x,y) coupled with at least one compaction coefficient K, the velocity scan can be considered as a suite of scaling factors to be applied to the initial values of Vo(x,y).

The same principle can be adopted for the determination of the anisotropic properties of the earth: Thomsen’s parameters ε and δ (Thomsen, 1986) can be scanned separately, or jointly if it is known a priori that they have a linear relationship (ε=n × δ). Furthermore, if the anisotropic properties depend on the layering, the use of a variable tilted axis of symmetry may simplify the result of the scans, as it will remove the structural effects. Azimuthal dependency of Thomsen’s parameters could also be assumed. The compaction coefficient, K, can also be included in a family of pseudo-anisotropic parameters, and could be scanned too. In fact, almost any parameter involved in the velocity parameterization can be scanned, but this does not mean that any parameter can thus be robustly determined.

Prior to the discussions concerning the velocity update techniques to be used, or those concerning the uniqueness of the inversion results, this work addresses the problem of the cost-effectiveness of the local velocity scan itself. This work shows that the set of traveltime tables corresponding to each of the velocity parameters scanned can be reconstructed from two traveltime tables only, with a reasonable degree of accuracy. Two different approaches can be followed. The first is based on a linearization of the traveltimes with respect to the velocity variations. The second is a hyperbolic interpolation based on the Dix hyperbolic equation (Mendes, 2000). The forward problem is solved a second time, but by using the velocity model at the extremum of the set of scaled models. The hyperbolic interpolation between traveltimes is directly performed in Vrms (or celerity, c = d/t, where d is the distance between the considered point and the source location), equivalent in this case to a linear interpolation in 1/t. Some numerical examples illustrate the range of validity of each method for different kinds of scanned parameters: velocity, compaction coefficient, and anisotropic parameters. Real data examples are shown.

### Traveltimes

The method presented here is intended to perform a velocity scan with an acceptable degree of accuracy with respect to the forward modeling solutions. If a ray tracing method solves the forward problem, the traveltine reconstruction task by interpolation may be impossible if the wavefront propagates in several branches which vary rapidly as a function of the velocity parameter.

In the examples, the modeling of the traveltimes is obtained by an eikonal solver. The same eikonal solver is used (Pica, 1998) within the weak anisotropy assumption. Orthorhombic anisotropy can be handled with a tilted axis of symmetry and azimuthal anisotropy dependence.
Traveltime interpolation in celerity

Hyperbolic traveltime interpolation (Mendes, 2000) is essential when it is applied between source or target locations, either in celerity, c=d/t, or in stacking slowness, s=t/d. For the velocity scans, traveltimes can be interpolated more easily as the two traveltime tables needed are at the same source and geophone location, on the same target grid. The interpolation problem can be examined in the homogeneous case: into a model $v_1$, the traveltimes are $t_1=d/v_1$, and in a second model $v_2$, $t_2=d/v_2$. In any model we have:

$$v = pv_1 + (1-p)v_2 \Rightarrow t = d / (pv_1 + (1-p)v_2) ,$$

the solution obtained by linear interpolation of the corresponding celerities, $c_1=v_1=d/t_1$ and $c_2=v_2=d/t_2$ into c, (and thus $t=d/c$) is thus exact. The linear interpolation in stacking slowness, $1/c$, which is strictly equivalent to an interpolation in time in this particular case (because $d$ is the same for the two traveltime tables), is not exact. And again, because $d$ is the same for the two traveltime tables, we can remark that the hyperbolic interpolation is in this case strictly equivalent to a linear interpolation in $1/t$. Obviously the interpolation in celerity between velocity parameters of any kind ($V_0(x,y)$, $K$, $\varepsilon$, $\delta$) is no more exact, but gives the best approximation, for a simple implementation. The maximum error found in each case inbetween the two extremes allows a relatively wide scan range. For $V_0$ and $K$ a range of scans from 0 to 40% remains accurate enough. This range is reduced to 20% for $\varepsilon$ and $\delta$ (figure 3).

Conclusion

Several velocity-related parameters can be scanned, such as the top-layer velocity, $V_0(x,y)$, the compaction coefficient, $K$, and Thomsen’s anisotropy parameters, $\varepsilon$ and $\delta$, by using only two traveltime tables, rather than by using the Green’s function corresponding to each of the scanned values. The reconstruction of traveltimes by linearizing the dependency on the model parameters allows a forward and backward extrapolation, but should be limited to the scan of constant velocities within a layer. A scan range of $\pm 15\%$ is suitable for this kind of method. The interpolation of traveltimes in celerity is more general and robust than the extrapolation. It allows a comfortable range of accuracy for $V_0$ and $K$ (up to 40% in some cases) as well as for the anisotropic parameters $\varepsilon$ and $\delta$ in the range of 20%.

References


Mendes M., 2000, Green’s functions interpolations for pre-stack imaging, Geophysical Prospecting, 48, 49-62.


Figures:

Figure 1a: Velocity model and traveltime isochrones to be reconstructed. The first traveltime table has been computed with the initial model, but replacing the velocity of the bottom layer by 3600 m/s instead of 4300. The first derivative was computed with an additional traveltime table, which used 3674 m/s in the last layer.

Figure 1b: Residual error after reconstruction using traveltime extrapolation. Contour intervals are every millisecond in the bottom layer. The correct velocity in the last layer was 16% higher than in the initial model.

Figure 2: velocity scan inside a salt dome. Surrounding structures remain unchanged while the base of the salt is imaged at a greater depth.

Figure 3: traveltime error between the reconstructed traveltime table obtained by celerity interpolation (between $\varepsilon=2\delta=0.$ and $\varepsilon=2\delta=0.4$) in the last layer, and the correct model ($\varepsilon=2\delta=0.2$). The traveltime error does not exceed 4ms at 4km offset, which represents an error of 0.15%.