

XTV inversion

To enable the realistic interpretation of sudden apparent velocity increase in CMP sorted traveltime curves, (Winkelmann 1998) proposes to extend the DeltatV gradient layer inversion (Gebrande 1986), with Dix inversion and Intercept Time inversion. These two additional inversion methods allow the **modeling of constant-velocity layers**.

As described by (Winkelmann 1998) and (Gawlas 2001), the XTV inversion reconstructs the 1D velocity vs. depth function $v(z)$ based on XTV data triples, with values X = (reduced) offset, T = (reduced) time and V = apparent velocity. These data triples sample a (reduced) CMP sorted traveltime curve. The inversion is based on the layer stripping principle.

XTV inversion is based on three different methods, for inversion of a data triple into a model layer :

- ▶ Modified Dix inversion
- ▶ Intercept Time inversion
- ▶ Gradient layer inversion (original DeltatV method)

The inversion starts with the first XTV triple at the smallest offset X , as determined from the original CMP curve. Once the first layer has been determined by one of above methods, offset and time for all other triples are reduced to the bottom of this first layer. Then the XTV triple at the next smallest offset X is inverted into a second layer, and remaining triples are reduced to the bottom of this second layer. This triple inversion process is continued iteratively, until all XTV triples have been processed.

We first describe each of these three inversion methods in detail. We then describe the overall XTV algorithm, which decides what inversion method should be applied to the current XTV triple. All inversion methods are described for the two-layer case only. Since the XTV inversion is based on layer stripping, we only need to deal with two layers (current overburden, current refractor) during each iteration and triple-to-layer inversion step.

The modified **Dix inversion assumes reflection of a ray**. The layer thickness h is determined as follows :

$$h = \frac{\Delta}{2} \sqrt{\frac{Vt}{\Delta} - 1}$$

Δ is the unsigned offset X between shot point and receiver.

t is the traveltime T between shot point and receiver, separated by offset Δ .

V is the measured apparent velocity, at the bottom of the layer i.e. at offset Δ .

The average layer velocity \bar{v} is obtained with

$$\bar{v} = \sqrt{\frac{V \Delta}{t}}.$$

Velocities at the top and at the bottom of the modeled layer are both set to this average velocity \bar{v} .

The **Intercept Time inversion assumes critical refraction of a ray**, with both overburden and basement layer having a constant velocity. Using intercept time τ as determined from the XTV triple with

$$\tau = t - \frac{\Delta}{V}$$

the layer thickness h is determined with

$$h = \frac{\tau}{2\sqrt{\left(\frac{1}{v_1}\right)^2 - \left(\frac{1}{V}\right)^2}}.$$

v_1 is the direct wave velocity (for first XTV triple) or the velocity as modeled for the bottom of the previously determined layer (for reduced XTV triples).

Velocities at the top and at the bottom of the modeled layer are both set to v_1 .

The **Gradient layer inversion method or DeltatV method assumes a diving wave ray and a constant velocity-gradient** equal to a. So the layer's velocity-depth function is

$$v(z) = a \cdot z + v_0 \quad (a = \text{const.})$$

Since the velocity gradient is assumed constant, the diving first-break ray follows a circle segment, between shot point and receiver. Based on the two equations

$$\Delta(V) = \frac{2}{a} \sqrt{V^2 - v_0^2}$$

and

$$t(V) = \frac{2}{a} \operatorname{arch}\left(\frac{V}{v_0}\right)$$

the velocity v_0 at the top of the modeled layer is determined numerically. Then the layer thickness h is

$$h = \frac{\Delta}{2} \sqrt{\frac{V - v_0}{V + v_0}},$$

and the velocity at the bottom of the modeled layer is set to the measured velocity V . v_0 can be smaller than the velocity measured at the bottom of the overlying layer. So the gradient layer inversion can recognize velocity inversions, at least in some situations. Also, the gradient layer inversion does not use the intercept time τ .

XTV parameter dialog

Display the *XTV parameter dialog* with *DeltatV|XTV parameters for constant-velocity layers* :

XTV Parameters dialog

☒ **Enable Modified Dix layer inversion**

Intercept time layer inversion

☒ **Enable Intercept time layer inversion**

Minimum velocity ratio : ratio

Minimum velocity increase : m/s

Multiple adjacent Intercept time layer inversion

☒ **Allow adjacent Intercept layer inversion**

Overlying layer velocity step : percent

Current layer velocity step : percent

☒ **Prefer measured layer top velocity over inverted**

Keep XTV for Auto DeltaV or force to Gradient model

☒ **Use above XTV settings for Automatic DeltaV**

Our **XTV inversion implementation** assumes that apparent velocity increases with offset. So XTV triples are sorted by offset, for layer inversion as described here. (Winkelmann 1998) proposes the following XTV inversion algorithm :

- ◆ Use Intercept Time inversion if the apparent velocity V increases suddenly, between adjacent XTV triples. The Minimum velocity ratio required for application of the Intercept Time layer inversion can be adjusted by the user. Set this to 1.01 to force application of Intercept Time method whenever possible. Intercept Time inversion can be disabled with XTV parameter Enable Intercept Time layer inversion.
- ◆ Use Dix inversion if both the average velocity \bar{v} (determined with Dix inversion) and the velocity v_0 at the top of the modeled layer (determined with Gradient layer inversion) are smaller than the velocity modeled for the bottom of the previously determined layer. You may disable Dix inversion with XTV parameter Enable Modified Dix layer inversion.

- ◆ Otherwise use DeltatV Gradient layer inversion.

Check which layer inversion method has been used for each XTV triple, in last column of file GRADIENT.TXT for [Smooth inversion](#), or DELTATV.TXT for [pseudo-2D DeltatV inversion](#) : 1=DeltatV Gradient, 2=Modified Dix reflection, 3=Intercept-time method.

A candidate XTV triple is [optionally rejected](#) using option [DeltatV/DeltatV Settings/Suppress velocity artefacts](#) if its apparent velocity V or intercept time τ are larger than average values for the next three XTV triples. This triple filtering has the aim of suppressing reflections erroneously picked as first breaks.

Intercept Time layer inversion for multiple adjacent XTV triples

v_1 as required for Intercept Time layer inversion is not clearly defined, especially if the previous layer has been obtained with Intercept Time inversion as well. You may suppress application of our Intercept Time inversion to multiple adjacent XTV triples, with XTV parameter [Allow adjacent Intercept time layer inversion](#).

. If the previous XTV triple was inverted with Intercept Time layer inversion as well, then the velocity v_1 for the bottom of the previous layer may be assumed to be the previous v_1 , or the apparent velocity V of the previous XTV triple, or any value between these two velocities. Alternatively, v_1 can be determined by interpolating between the previous v_1 and the apparent velocity V of the current XTV triple.

You may specify how v_1 should be determined with XTV parameters [Overlying layer velocity step](#) and [Current layer velocity step](#).

If the resulting v_1 exceeds the previous apparent velocity V , v_1 used for inversion of the current XTV triple is reset to V of the previous triple.

The XTV inversion ensures that the sum of [Overlying layer velocity step](#) and [Current layer velocity step](#) does not exceed 100%.

If you want to use apparent velocities V (from previous and current XTV triples) exclusively and disregard previous v_1 , for determination of the current v_1 based on step parameters [Overlying layer velocity step](#) and [Current layer velocity step](#), just enable XTV option [Prefer measured layer top velocity over inverted](#). If this option is enabled, the apparent velocity V as obtained for the previous XTV triple and layer is taken as an estimate for the velocity at the top of the current layer. In analogy, the velocity at the top of the previous layer is estimated with the apparent velocity V of the previous-previous XTV triple.

Click button [Gradient model](#) to reset XTV inversion parameters to settings optimized for gradient layer inversion, assuming diving waves and using DeltatV Gradient layer inversion.

Click button [Layer model](#) to reset XTV inversion parameters to settings optimized for constant-velocity layer inversion, using Intercept-Time inversion whenever possible.

Use edited XTV settings for Automatic DeltatV inversion

[XTV parameters](#) are always used for inversion with [DeltatV/Interactive DeltatV](#).

To force [DeltatV/Automatic DeltatV and WET inversion](#) to regard your edited [XTV inversion parameters](#) as shown above, you need to check XTV option [Use above XTV settings for Automatic DeltatV](#). This option is available in our version 4.03 software released in July 2022 only.

If you leave this option unchecked or in earlier versions of our software not offering this option, menu item *DeltatV/Automatic DeltatV and WET inversion* will internally reset XTV inversion options to settings obtained by clicking button [Gradient model](#) in above XTV parameters dialog.

See our 2022 tutorial https://rayfract.com/tutorials/NGU_G1.pdf for DeltatV+XTV inversion assuming constant-velocity layers (Fig. 23 and Fig. 25 in NGU_G1.pdf), of synthetic first break picks forward-modeled over NGU G1_SYNTHETHIC.GRD. We set XTV parameter [Minimum velocity ratio](#) to 1.05 and 1.10 respectively, for Fig. 23 and Fig. 25. See Fig. 27 in NGU_G1.pdf tutorial.

Model sharp velocity contrast between overburden and basement with Smooth XTV inversion

To image a sudden velocity increase at bottom of weathering overburden in your 1D initial model for Smooth inversion :

- ◆ check [Smooth invert/Smooth inversion Settings/Allow XTV inversion for 1D initial model](#)
- ◆ uncheck [Smooth invert/Smooth inversion Settings/Interpolate velocity for 1D-gradient initial model](#)
- ◆ uncheck [DeltatV/DeltatV Settings/Reduced offset 0.0 is valid trace with time 0.0](#)
- ◆ select *DeltatV/XTV parameters for constant-velocity layers...* to display [XTV parameters dialog](#)
- ◆ click button [Layer model](#) to reset XTV inversion parameters to settings optimized for constant-velocity layer inversion, using Intercept-Time inversion whenever possible
- ◆ click *Accept* button

Alternatively edit [XTV parameters](#) controls as follows :

- ◆ check box *Enable Modified Dix layer inversion*
- ◆ check box *Enable Intercept time layer inversion*
- ◆ check box *Allow adjacent Intercept time layer inversion* to realistically image this velocity jump
- ◆ set *Minimum velocity ratio* to 1.01 to use intercept-time method whenever possible
- ◆ click *Accept button*

- ◆ now run *Smooth invert/WET with 1D-gradient initial model* and confirm prompts as usual

Instead of editing *XTV parameters* as described above you can also

- ◆ check *Smooth invert/Smooth inversion Settings/Allow XTV inversion for 1D initial model*
- ◆ check *Smooth invert/Smooth inversion Settings/Optimize XTV for layered starting model*
- ◆ select *Smooth invert/WET with 1D-gradient initial model* and confirm prompts as usual

See our tutorial <https://rayfract.com/tutorials/jenny10.pdf> for detailed and illustrated instructions. This also shows **imaging artefacts caused solely by Golden Software Surfer Kriging gridding method**. Natural Neighbor gridding method works much better, at least in this case, for imaging of pseudo-2D XTV inversion output.