Implementing Extended Elastic Impedance in CE7

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**EXTENDED ELASTIC IMPEDANCE**


- The basic idea is that although the typical incident angle range for seismic data is from 0° to 30°, theoretically we can extend this over a greater range of angles, x, such as –90° to +90°.

![Graph](image)

(from Whitcombe et al, Geophysics, 2002)

- The \( \sin^2 \theta \) term in the Zoeppritz linear approximation limits the range at which reflectivities can be defined.

If we re-write the Zoeppritz linear approximation as \( R = A + B \tan x \) and then scale it by \( \cos x \) we can create the **scaled reflectivity equation**:

\[
R_s = A \cos x + B \sin x
\]
Similar to Elastic Impedance, we can also create “Extended Elastic Impedance Logs” from the P-wave, S-wave and density logs for each angle $\chi$ from the scaled reflectivity equation using the following equation:

$$EEI(\chi) = \alpha_0 \rho_0 \left[ \left( \frac{\alpha}{\alpha_0} \right)^p \left( \frac{\beta}{\beta_0} \right)^q \left( \frac{\rho}{\rho_0} \right)^r \right],$$

where

$$p = (\cos \chi + \sin \chi),$$
$$q = -8K \sin \chi,$$
$$r = (\cos \chi - 4K \sin \chi).$$

...and generate a spectrum of EEI logs.

(from Whitcombe et al, Geophysics, 2002)
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There are two methods for determining what angle $\chi$ to use in order to best delineate the reservoir parameter reflectivity section.

1. By generating the EEI log spectrum and cross-correlating the log reflectivities with the desired reservoir parameter reflectivity.

2. By generating the scaled reflectivity seismic spectrum at each well location and cross-correlating with the desired reservoir parameter reflectivity.

- The second method is preferable for practical purposes since noise in the seismic section, anisotropy, velocity errors, etc..., may yield an optimum angle that is different than that achieved by the cross-correlating the EEI logs.

- When we have determined $\chi$, we can then create the equivalent seismic reflectivity section from the combination of intercept and gradient stacks using the $R = A + B \tan \chi$ equation.

- Using the new Hampson-Russell CE7 software and some Trace Maths scripts, we can implement both methods of the Extended Elastic Impedance method and generate the desired reflectivity section.
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To start, you need a well with a P-wave, Density, S-wave, and the log that you wish to create the reflectivity section (i.e., Vp/Vs, Sw, λ, μ, κ, φ, AI, SI, etc...)…
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Now open the CE7 AVO version and build a 3D depth model using the Advanced Setup...
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Select the well from the database...
...and build the geometry.

The first trick to making this process work is to have something in the header that can be related to angle. In this example, I have built a model with 181 traces that start from $X = -90$ to $X = 90$. The $X$ value will now correspond to the angle...
Select the logs for the model: P-wave, Density, S-wave. The second trick is to also include the other logs that you wish to correlate with...
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Make a note of the sample rate that you are using. In this case, my volume is sampled every 0.20 m...
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Map the well to the location corresponding to 0° (i.e., the Acoustic Impedance location)...
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Now apply a Trace Maths script to the P-wave, Density and S-wave log volumes to create the EEI log spectrum.

** Rename the volume variables to P_wave, Density and S_wave as shown...**
You may want to call the output something useful like `EEI_logs`...
Load the EEI.prs file from the Trace Maths directory into the parser window.

If you made your X's equal to your angles and if you renamed the volume variables, then you do not have to change anything in this script...

This script calculates the K value for you. If you want to hard-code your K, edit this part here.
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The result is the spectrum of Elastic Impedance logs ranging form –90° to +90°. I have changed the Inserted Curve to the P-Impedance log for a comparison.
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Now use another Trace Maths script to cross-correlate one of the other logs in the depth model against the EEI log suite. In my example, I will first cross-correlate the EEI logs with the Porosity log volume.

Change the EEI logs volume variable name to ref and the other log volume to input and set the Usage of both to used. Change the output name to something useful like xcor_por to indicate that it is the cross-correlation of the porosity logs with the EEI logs...
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The Trace Maths script, crossCorrelateReflectivity, is referenced to the depths.

This is where you set your parameters. In this example, my sample rate, \( s_{\text{int}} \), is 0.20 m. I am starting the correlation window at \( \text{inputStartDepth} = 550 \) m and the window ends at \( \text{inputEndDepth} = 710 \) m. The cross-correlation coefficients are going to be output at \( \text{outputStartDepth} = 160 \) m depth in the output volume.

I’ve set the delay (\( \text{maxDelay} \)) to 0 to just do a straight cross-correlation...

```c
/* USER PARAMETERS: */
/**/ /* USER PARAMETERS: */

/* crossCorrelateReflectivity Trace Maths Script */
/* @ Kevin Goritz 2004 */

/* This script calculates the reflectivity of two depth */
/* traces and cross-correlates them. */
/* This requires two input depth volumes that must be named correctly. */

/* INPUT VOLUMES: */
/* input => primary input */
/* ref => the volume to correlate with */

/****************************************************************************
/* USER PARAMETERS: */
/****************************************************************************

/* depth sample interval */
s_int = 0.2;

/* constant window start depth */
inputStartDepth = 550;

/* constant window end depth */
inputEndDepth = 710;

/* the starting point for outputting the values */
outputStartDepth = 160;

/* correlation will be calculated from -maxDelay to +maxDelay */
maxDelay = 0;

/****************************************************************************
/* Cross Correlation Calculation */
/* Don’t change anything below! */
/****************************************************************************

/* convert depths to sample number and calculate the window length */
/* N.B.: assumes that the volume starts at depth = 0 */
ulen = ( inputEndDepth - inputStartDepth ) / s_int;
inputStart = inputStartDepth / s_int;
outputStart = outputStartDepth / s_int;

/* Initialize the output and reflectivity volumes: */
output = input * 0.0;
inputE = input * 0.0;
refE = input * 0.0;

/* calculate the reflectivity series... */
i = 0;
TraceLength = numSamples( input );
while( i < traceLength )
{
    if( i < traceLength - 1 )
    {
        /* calculate reflectivity */
```
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The output probably won’t look to interesting. You’ll have to change some of the view parameters like the zoom, Mean and Std, turn off fill trace and color interpolation, etc…
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To get something that looks a bit better...
Now cross-correlate the EEI logs with the some other logs. In this example, I’ll now cross-plot against a lithology indicator log like the Gamma Ray...
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The gamma ray reflectivity log cross-correlated with the EEI reflectivity logs.
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It’s probably best to view the cross-correlation results in a Cross-Plot display. Bring both cross-correlation results into the cross-plot window...
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Now click on the New Plot > Primary Data to make a crossplot of the X-coord on the X-axis and the cross-correlation results on the Y-axis.
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The cross-correlation of the Porosity reflectivity with the EEI reflectivity log spectrum

A zoomed in view shows the maximum negative correlation at 45°...
The cross-correlation of the Gamma Ray reflectivity log with the EEI reflectivity log spectrum.

A zoomed in view shows the maximum correlation at 65°...
Here, I cross-correlated the P-Impedance reflectivity log against the EEI reflectivity log spectrum. As expected, we get a perfect correlation at 0°...
We can now compute the associated elastic parameter reflectivity volumes using Trace Maths applied to the A & B AVO attribute volumes...
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To compute the porosity reflectivity, I’ve renamed the AVO Intercept and Gradient volume variables to A & B…
And type in the equation: \(-1^\ast (A + B\ast \tan(45 \ast \pi / 180))\). In this case, the maximum correlation was a negative value so I have negated the results...
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The porosity reflectivity volume...
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As well, I’ll compute the lithology reflectivity...
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The lithology reflectivity volume...
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In Strata we can invert these volumes to yield...
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The inverted porosity volume
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The inverted lithology volume
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And an interpretation volume from the cross-plot.
Multi-well models can also be created. In this example, I’ve placed each well at the end of separate cross-lines...
You’ll have to find some way to over-ride the log interpolation method. I put all my wells at \( X = -91 \) and used the Triangulation interpolation scheme. I’ll do all subsequent processing starting at Inline 2 (i.e., \( X = -90 \))...
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Here’s the cross-correlation of the porosity reflectivity for 12 wells against the EEI reflectivity log spectrum. It’s up to you to determine which cross-line corresponds to which Well. The Well in blue does not have a porosity log.
The second method of EEI involves creating the scaled reflectivity trace spectrum volume from the AVO A & B attributes and cross-correlating them with the logs.

To test this method, I’ve created a synthetic gather and extracted the AVO attributes....
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Convert both the AVO A and B attributes to the Depth domain using Process > Utility > Time to Depth Conversion...
Now build the depth model using all the logs. I’ve created a model with 182 traces starting from $X = -91$ to $X = 90$. 
Now we have to make the AVO A & B volumes the same size as the Depth Model. Use Process > Utility > Concatenate and copy the trace 181 times...
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Here’s the new AVO A & B traces in depth copied 181 times.
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Now use Trace Maths to create the scaled reflectivity volume from the A & B AVO attribute volumes.
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Call the output something useful – like `scaled_reflectivity`

And type in the script.
In this case, I refer the angle to the inline values...

```
rA = rad( inline - 91 );
output = A * cos( rA ) + B * sin( rA );
output;
```
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The scaled reflectivity volume should change from one side to the other such that troughs become peaks and vice versa...
Another test to determine if the scaled_reflectivity was calculated correctly is to open the AVO A volume and view the difference between the two traces. The two should cancel each other out at 0 degrees...
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Now use Trace Maths to cross-correlate the scaled reflectivity with the target log. In my case, I will test this with the P-Impedance log curve...

For this particular script to work, you should name the scaled reflectivity volume **seismic** and the target log volume should be called **logs**...
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Call the output something useful...

and load in the following script:

crossCorrelateLogReflectivityWSeismic
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This script is similar to the other cross-correlation trace maths script – but it calculates the reflectivity of the logs volume and cross-correlates it with the seismic volume – make sure that the logs volume is renamed as logs and that the scaled reflectivity volume is renamed as seismic.

Again, only edit the values in the USER-DEFINED PARAMETERS section.
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Cross-plot the resulting cross-correlation volume against itself and adjust the plot parameters to plot the X-Coord on the X-axis. As expected, we see the greatest positive correlation at nearly 0 degrees.
This approach can probably be applied to multiple wells in a seismic volume. I will not demonstrate this whole process – because I don’t have an appropriate data set.

First extract an arbitrary line on the AVO attribute volume that goes through all the wells and only extracts at the node points...
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Because the arbitrary line still has inline/xline information tied to the original seismic cube, you will have to read it in again from the SEGY file and overwrite the Inline/Xline information...

I’ve set the origin to \((-100, 0)\) with a spacing of 10 m and with the wells oriented along the Y-axis...
Next, I’ll use the concatenation process to repeat the inline 181 times to create a range of \( x \)'s from \(-91\) to \(+90\)...
I'll remap the wells to the first inline at $X = -100 \ldots$
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And build the log model volume. Then apply the cross-correlation script as before.
Thanks to

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