Geol 335.3

Lab #6: Common mid-point method

In this lab, you will use simple Matlab or Octave simulations to study the principle of the common-midpoint (CMP) reflection method. Tools and functions from the previous labs will be useful in this exercise.

Theory

Unlike the common-shot seismic data studied in the previous lab, CMP records are collected by moving both sources and receivers in opposite directions so that their midpoint remains constant while the source-receiver distance increases. CMP gathers are usually presented in the form of time-offset seismic sections.

The primary use of CMP gathers is for *stacking velocity analysis*. In its simplest form, velocity analysis is performed by trying multiple pairs of normal-incidence reflection times (t_0) and stacking velocities V, and for each of them, calculating some "semblance" function representing the degree of signal coherence along the hyperbola. The pair (t_0, V) giving the largest semblance identifies a reflector at depth $z = t_0 V/2$, with average velocity V above it.

There are many ways to calculate the semblance function from seismic records. For example, the stack (summation) of signal powers along the reflection hyperbola can be used:

$$Semblance(t_0, V) = \frac{1}{N}\sum_{i=1}^{N} u_i^2\left(\sqrt{t_0^2 + \left(\frac{x_i}{V}\right)^2}\right) \quad , \tag{1}$$

where $u_i(t)$ is the signal it i^{th} channel, and x_i is the source-receiver offset at its location. In this lab, we use a different measure of semblance which provides smoother peaks:

$$Semblance(t_0, V) = const \times smooth\left\{\left[\sum_{i=1}^{N} u_i\left(\sqrt{t_0^2 + \left(\frac{x_i}{V}\right)^2}\right)\right]^2\right\}. \tag{2}$$

This is a smoothed squared stack of the waveforms evaluated along the reflection hyperbola.

For a horizontal reflector, the stacking velocity equals the averaged (in the sense discussed in class) velocity above it. When reflector dip α is present, the stacking velocity increases:

$$V_{\text{with dip}} = \frac{V_{\text{no dip}}}{\cos\alpha}. \tag{3}$$

Code

In another copy of your `model1.m` file (from lab 5), rename `sources` to `midpoints`. For each midpoint number `n`, you can obtain a CMP section by using a small modification of function `reflection(…)` called `reflection_CMP(…)`. In this function, source positions are variable for each receiver, so that <u>the midpoint is fixed</u>. For example, for the first midpoint (denoted `midpoints(1)` in your code), the resulting section will be produced by

```
sec = reflection_CMP(midpoints(1),receivers,layer,2.0);
```
(4)

To plot this section, you will need to first calculate the relative source-receiver distances (verify that this formula is correct!):

```
offsets(1,:) = 2*(receivers - midpoints(1))
```
(5)

Then, the plot is obtained by:

```
plot_section(offsets(1,:),sec,'Offset (m)','b-')
```

To compute the velocity spectra in eq. (2), we provide function `semblance()`. Look into its code. Note that it is constructed very similarly to `reflection()`, by first initializing a blank semblance and then adding to it contributions from all traces using `interp1()`. The output of `semblance()` also represents a trace section, which can be plotted by `plot_section()`:

```
plot_section(V, sec,'V(km/s)','b-'),
```

where `V` is the array of trial stacking velocities.

Assignments

Download and unpack archive file [lab6.zip](lab6.zip). Start with file `model1.m` and following its examples and commentaries, do the following:

1. [5%] Put three points (or more if you like) into array `midpoints`. Complete the `for` loop in the code to calculate the source-receiver offsets by formula (5) above.
2. [5%] Execute the modified script `model1.m` and pick three horizontal reflecting boundaries. To pick any boundary, click at two points and then press spacebar. Place the first boundary `layer1` <u>in the bottom half of the section</u>, and `layer2` and `layer3` at a shallow depth.

Function `picklayer(…)` has been modified so that if a pick is made within about 7% of the edge of the model area, the boundary will be extended to the edge. This allows avoiding undesired "diffraction hyperbolas" from the edges of the model area.

After you have picked the boundaries, you can set variable `pick_layer = false`, and the picked boundaries will be re-loaded next time you run the script.

3. [20%] For one midpoint near the middle of the line, generate reflection sections (by using `reflection_CMP()`) with different velocities. Try several values of velocity to see how they affect the shapes of reflections.

Note that not all combinations of velocities are possible. The relative variations of velocities should be smaller than those of layer depths, so that the zero-offset reflection travel times (seen at the apexes of reflection hyperbolas) should decrease from `layer1` to `layer 3`. You can start from values 2.5, 2.0, and 1.5 and adjust them to achieve good images.

After modeling `sec1`, `sec2`, and `sec3`, sum them together:

`section` = `sec` + `sec2` + `sec3`

This summation should illustrate how reflections from different depths overlap in real seismic data.

4. **Note in the report** how the times of reflections at zero source-receiver offsets (t_0) correspond to the depths of reflectors, and the moveouts (slopes) of reflection hyperbolas correspond to the lower or higher velocities.

The resulting section will be saved in `model1.mat` file, and the following velocity analysis steps you can do in script `model2.m`. This script will not have to re-compute the synthetics and will run faster.

5. [10%] In script `model2.m`, compete the call to `semblance()`, which uses the CMP gather `section` to **compute and plot the semblance spectrum** (eq. 2) for stacking velocities `V=0.7:0.05:3.0 m/ms` (note that these units are the same as km/s). Try denser spacings of velocities and larger upper limit to obtain better images.

In the resulting figure, you should see three subplots: the input reflection section, the semblance plotted as a seismic section (also using `plot_section(…)` function), and a color image of the semblance using `imagesc()` function. A reversed color map called 'hot' is used. Note this easy and handy way of plotting images in Matlab.

6. [10%] Using the interactive Matlab figure, point the mouse at the maxima of semblance and read values of t_0 and V (stacking velocity) for the measured reflections.

   a) **Put the measured t_0 and V for each reflector** in your lab report and **comment** whether these values match the actual parameters of the model.

b) From semblance plots, **describe the velocity resolution** (width of velocity peaks) varies with t_0 and velocity. For which reflections the velocity can be determined most accurately? Again using computer mouse, **estimate the errors** in stacking-velocities values.

7. [20%] Run `model1.m` again and **pick two points to make a dipping reflecting boundary** close to the depth of the middle reflector in the preceding test. Plot the common-midpoint gather. **Answer the following questions**:

   a) Is the shape of the reflection symmetric? Is it visibly different from the horizontal-reflector case?

   b) Is the apex of the reflection hyperbola shifted up-dip as it was for common-shot recording in Lab 5? Can you explain why it is shifted or not?

The effect of the dip consists in making the <u>stacking velocity faster</u>; that is, the reflection hyperbola will be flatter for steeper dip. This increase of velocity may be difficult to see directly but <u>it can be measured by using velocity analysis</u> in the next step.

8. [10%] **Plot the semblance spectrum** for the dipping interface case. How do the optimal stacking velocity change? Compare the result to the prediction from formula (3).

9. [10%] **Summarize** the differences of the horizontal and dipping-reflector cases in CMP gathers.

Next, look into and **execute script** `model3.m` . It is similar to `model1.m` and contains a (somewhat simplified) simulation of the whole zero-offset seismic section (ZOS). The ZOS represents the result of placing a source at each midpoint position and recording reflections on a receiver located at the same midpoint. This type of section represents the (almost) final output of reflection seismic imaging and <u>approximates the geological or structural layering of the subsurface</u>.

In script `model3.m`, only two reflecting boundaries are simulated but you can add another one if you wish. Pick the boundaries interactively making a horizontal reflector and a steep "fault" approaching it like shown in the following Figure.

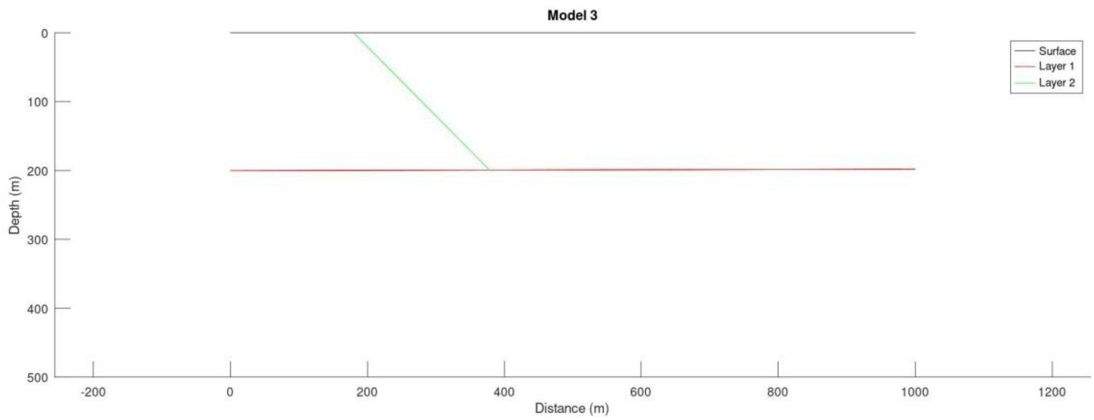

Figure 1. Horizontal reflector (red) and a steep fault (green).

By again setting `pick_layer = false`, you can skip the interactive picking when repeating further processing steps.

In `model3.m`, times t in the data section (vertical axis) are transformed into "pseudo-depth" $z = Vt/2$. This pseudo-depth represents the depth of reflection at vertical wave propagation in a constant-velocity medium with velocity V. Plotting times with such scaling is called "1:1 scaling" and common in reflection seismic imaging. With such scaling, horizontal reflections appear at their correct positions in the geological section.

10. [10%] Examine the resulting pseudo-depth section.

    a) **Mark on the plot** all resulting events (groups of blue seismic wiggles): reflections from the horizontal and dipping boundaries, diffractions from the edges of the dipping reflector (green in Figure 1).

    Comment on the similarities and differences between the positions and dips of these reflections (red lines) reflectors and the resulting reflections (blue seismic wiggles):

    b) For the horizontal boundary (red in Figure 1), does CMP reflection imaging accurately reveal its position?

    c) Are the true reflectors deeper or shallower than the apparent ones (those seen in the ZOS)?

    d) Are true reflectors more or less steep than those seen in the ZOS?

    e) Use a protractor or Matlab to measure the dip angles of the true reflectors and the apparent ones. Verify whether these dips satisfy relation

    $$\tan\left(Dip_{\text{apparent}}\right) = \sin\left(Dip_{\text{true}}\right). \tag{6}$$

    f) For diffractions coming from the endpoints of the dipping fault, are the slopes of the far-away tails close to 45°?

Hand in:

Zipped directories containing:

1. Matlab codes ("m-files") which you have modified;
2. Discussion in a Word file including Screen captures or jpeg/PDF figures.