Geol 335.3

Lab 2 – Travel-time Interpretation of Seismic Data

The purpose of this exercise is to identify events and provide an interpretation of seismic shot records. You were given two plots of the same seismic reflection record from one shot: unscaled and with exponential scaling applied to compensate the geometrical spreading.

The data set was acquired using a symmetric split-spread geometry, which means that the source was located near the middle of the geophone spread. The offset is in meters, and the trace (geophone) spacings are 20 m.

In the following work steps, use colored pencils, pens, or highlighters to indicate the different seismic wave arrivals.

1. [5%] Compare the unscaled and scaled data plots. Comment on the features which you see better or worse on these plots (recognize wave arrivals on top of noise, variations of amplitudes, travel times, slopes of travel-time curves)

   Note that a well-designed data display is an important component of seismic processing and interpretation. Even with a simple change in scaling like in this lab, the records reveal different aspects of the data.

2. [5%] Determine near which channel shot 163 was fired. Mark the shot location with a flag on the top margin of the plot.

3. [10%] **Identify all linear events** (those aligned along approximately straight lines in (*T*,*X*) plane):

   a. Refractions; note any changes in time-distance moveouts;

   b. Ground roll. This is a band of strong and low-frequency arrivals with very large moveout (low velocity).

4. [5%] Locate the cross-over points if they exist (the distances where deeper refractions overtake other refractions or direct waves).

5. [10%] Use a ruler to reasonably accurately pick the coordinates and times of the first breaks in the plots. Plot them on a *T*-*X* diagram (time vs. offset plot). <u>Use Matlab</u> (recommended) or Excel for plotting.

   Accurate picking may be a bit complicated by the extrusions of the "wiggle" graphs to the left and right of receiver locations. Try ignoring these extrusions and place time picks at the positions of receivers.

6. [10%] Calculate the apparent velocity of each linear event, including the ground roll. The apparent velocity equals 1/slope on the *T*-*X* diagram.

7. [5%] **Identify two reflection hyperbolas**. One of them is quite clear and the other maybe a little spotty. Just mark the intervals where you see them.
8. [10%] Pick the arrival times of these reflections and compute their stacking velocities using the $X^2 - T^2$ analysis (for explanations of the method, see the end of this document).

   Pick only several (~10) points at various receiver positions. Use Matlab or Excel for calculations and plotting.
9. [35%] Combine the refraction and reflection results in a final velocity model. Comment on the agreement between refraction and reflection travel-time data.
10. [5%] Estimate the frequency of the noisy trace on channel 96. (Count the number of periods n per T = 200 ms, and the frequency will be $f = n/T$). Based on the frequency, can you guess **what is the likely cause of this noise**?
11. **Bonus 5%**: Investigate the dispersion character of the ground roll. Dispersion describes the type of wave propagation in which the waveform is continuously changing its shape. The dispersion can be recognized from the difference between the *phase velocities* and *group velocities* of the waves. Try identifying the group and phase velocities of the ground roll in the plots. **Are they phase and group velocities different**? If they are different, **which of them is faster**?

    Group (signal) velocity is the velocity of propagation of the wave energy packet. In the data, you can identify this velocity by drawing a straight line starting from the source position at t = 0 and following the onset of the ground roll.

    By contrast, phase velocity is the velocity of a single-frequency, harmonic signal. This velocity is not directly seen in the data. However, a good approximation for is obtained if you draw straight lines following the same "phases" of the wave, i.e., for example, positive or negative peaks or zero crossings. Try drawing such lines in the ground-roll records and estimating their slopes.

Methods:

X-T method for determining the shallow structure using refractions

In the *X-T* method, all travel-time dependencies are of the form of linear functions:

$$t(x) = t_{\text{int}} + px,$$

where $t_{\text{int}} = t(0)$ is the intercept time (point of graphical intersection of the straight line $t(x)$ with the time axis) and p is the ray parameter. If we consider a layered model with velocities V_1, V_2, V_3, etc., then $p = \frac{1}{V_1}$ for the direct wave (for which also $t_{\text{int}} = 0$), and $p = \frac{1}{V_{k+1}}$ for refraction (head wave) occurring on boundary number k. The intercept time for this refraction is accumulated from the top of the model to the k-th boundary:

$$t_{\text{int}} = \sum_{i=1}^{k} \frac{2h_i}{V_i} \cos\theta_i = \frac{2h_1}{V_1} \cos\theta_1 + \frac{2h_2}{V_2} \cos\theta_2 + \ldots, \qquad (**)$$

where h_i are the thicknesses of the layers. Angles of the rays in each layer are determined from parameter p:

$$\sin\theta_i = pV_i,$$

and consequently $\cos\theta_i = \sqrt{1 - (pV_i)^2}$.

Using the above relations, you can derive the layered structure (parameters h_i and V_i) starting from the top of the model and proceeding downward as follows:

1) From the data, measure the moveout (slope) of the direct-wave travel times p_1 and obtain the velocity of the shallowest layer $V_1 = \frac{1}{p_1}$.
2) Measure the moveout p_2 of the first headwave (refracting on top of layer 2) and determine the layer velocity: $V_2 = \frac{1}{p_2}$;
3) Determine the angles θ_i in the layers above the current one (only one layer right now);
4) Using eq. (**), determine the intercept time $t_{\text{int}}^{\text{known}}$ using all layers for which you already know the thicknesses h_i (none of them during the first pass);
5) Measure from data the intercept time t_{int} for the current refractor;
6) From the measured t_{int} and modeled $t_{\text{int}}^{\text{known}}$ obtain layer thickness using an inverse of eq. (**): $h_i = \left(t_{\text{int}} - t_{\text{int}}^{\text{known}}\right) \frac{V_i}{2\cos\theta_i}$;
7) Repeat steps 2) – 7) for other branches of head waves.

X^2-T^2 method for determining the deeper structure from reflections

This method utilizes the hyperbolic shape of a reflection in the (X,T) plane in order to estimate the optimum ("stacking") velocity and depth. Only a single-layer model is considered. Travel time of the reflection recorded at offset x from the source is (from the Pythagorean theorem):

$$t(x) = \frac{2}{V_1} \sqrt{Z_1^2 + \left(\frac{x}{2}\right)^2}.$$

This equation describes a hyperbola $t(x)$. If we consider t^2 as a function of x^2 instead, the relation becomes:

$$t^2 = \frac{4Z_1^2}{V_1^2} + \frac{x^2}{V_1^2}$$

which is <u>an equation of a straight line in the plane of squared variables</u> (x^2,t^2). From the slope of this line from axis x^2, you can determine V_1:

$$V_1 = \frac{1}{\sqrt{slope}} ,$$

and from its zero-offset intercept value, $intercept = \frac{4Z_1^2}{V_1^2}$, determine the depth of reflection Z_1:

$$Z_1 = \frac{1}{2} V_1 \times \sqrt{intercept} \, .$$

Hand in:

Annotated plots and write-up in a binder, or Word or PDF file by email.