GEOL 384.3 and GEOL 334.3

Lab #10: Seismic Experiments in Classroom

In this lab, you will conduct two types of seismic experiments in classroom Geology 265, look at the seismograms, and perform simple analysis of the data. The experiments will simulate at small scales and short times the procedures commonly used in seismic investigations: laying out receiver spreads, measuring their coordinates, activating several types of sources, recording and various displays of the data, filtering the seismograms, and looking for their features related to some useful properties of the subsurface.

The first experiment will be conducted on the lab table and simulate a "refraction" line for shallow seismic investigation. As in any refraction work, you will:

- Examine the waveforms at different locations on the table and relate them to the structure of the "subsurface";
- Compare the waveforms produced by different sources and measure their spectra;
- Apply filtering and cross-correlations to the records;
- try several types of impulsive sources (rock, weight drop, or even knuckles), and a vibrator.
- Estimate the wave speed within the table. This is the ultimate goal of refraction seismic investigation.

In the second experiment, you will try locating seismic events on the floor. This experiment will be a miniature model of how earthquakes are located in many real Earth's settings:

- for the whole Earth (global scale),
- regionally (within about 1000 km distances from seismic stations),
- locally (within about 150 km),
- on the scale of a mine or fluid injection well (scale of about 0.1 – 1 km),
- and all the way to the scales of acoustic-emissions experiment with rock cores (~10 cm).

In this experiment, the goals will be to estimate the wave velocity within the floor and locations of "microearthquakes", which will be produced by striking the floor with a hammer or simply stomping.

Equipment and software

We will use an 8-channel seismic recording system that we built ourselves recently. As receivers, we will use 40-Hz accelerometers.

The recording system will digitize the signal at frequency near 10 kHz. In signal analysis, there is the important, so-called Nyquist-Shannon criterion stating that for correct recording of a signal, one must have more than two samples per the shortest recorded wave period. Therefore, with 10 kHz sampling, we will have a fairly broad band of about 5 kHz for recording (more precisely, about 4.5 kHz due to the "anti-aliasing filter"). Note that in real seismic work on the ground, you will unlikely get frequencies over 1 kHz, and so the

4.5-kHz band is actually very good. However, because of working with short distances and hard materials (fast wave speeds), we need to try getting as high frequencies as we can. Recording times will be 2 seconds, and this duration can be easily changed.

The display in the seismograph software allows some basic processing: filtering, cross-correlation of the record with a selected channel, auto-picking arrivals, and time-shifting the records by these picks. These options are available under buttons “Display settings” and “Process” -> “Current record”.

Experiment 1: table-top seismic line

1) Help setting up the recording equipment and video connection to the screen projector in the classroom. **Place the 8 receivers in a line** along the middle of the lab table and plan locations of 4–5 source points around this line. Use measuring tape to **measure the coordinates** of receivers and source points. **Sketch the layout in your workbook** and provide the coordinates for entry in the recording computer.

2) **Use a light hammer or a small piece of rock** to lightly strike the table at each of the source points.

   Before each strike, the recorder will need to be “Armed”, and then the recording is started by pressing “Trigger now”. Because we have no proper triggering device to start the records automatically, we will simply strike within the 2-second time window and measure the actual time of the strike from the records.

In the following steps, **make screen captures[1]** to illustrate the important observations and include the screenshots in your report.

3) For each recorded source, **carefully look at the records**. Select display parameters which would allow the best view of the records.

   a. **Identify the time of wave arrival** in each channel and evaluate how accurately it is picked with the available automatic methods. For this, the display may need to be strongly zoomed in.

   b. **Evaluate the time and position of the source.** The software should show this time by a green circle, and so you need to simply **explain the principle of this location** and evaluate whether it looks correct from the records.

   c. Examine the waveforms: **Measure the duration of the primary pulse between zero crossings** t_{pulse} and the period or reverberations. From t_{pulse}, **estimate the frequency bandwidth** of recording as $f = 1/t_{pulse}$. Make sure to use correct units of this quantity.

   d. <u>**GEOL 334 students:**</u> Note that the recorded waveforms consist of initial pulses (with fast oscillations) followed by steadier and lower-frequency oscillations. These oscillations should be produced by resonances within the structure of the table. **Do these resonances correlate with sensor positions on the table**? **Try using low-pass or high-pass filtering** in the display to emphasize or suppress these resonances.

4) Using your sketch of experiment geometry and screen snapshots or the records from sources, **estimate the wave velocity within the table**. The velocity is obtained by taking some points

[1] I will be operating the recorder and making snapshots for your data analysis.

spaced by distance Δx along the profile, measuring the time difference Δt for the wave passing through these points, and taking ratio

$$V = \frac{\Delta x}{\Delta t}\,. \tag{1}$$

This velocity is also estimated by the software and shown by dashed lines in the display. **Compare the value you obtain from eq. (1) and the one shown in the screen shot**.

Try seeing whether you can recognize P- and S-waves in the records. P wave should usually be faster than S wave by about 1.5 – 2 times – see whether you can detect hints of this faster but weaker wave. This may be difficult; I think you will likely only see the S-wave.

5) **<u>GEOL334 students</u>: Answer this question**: why do I say the wave in the table should be the S wave?

   Hint: note the direction of displacements (vertical) which we are recording by the accelertoeters.

6) **<u>GEOL334 students</u>:** Look at the "Amplitudes in channels" plot at the bottom of display. **How does the amplitude of accelerometer shaking vary** with their positions on the table and distances from the source? Does this variation make sense to you? **Calculate the amplitude ratio** between the strongest and weakest signals recorded on the table.

Note that this amplitude plot is in decibels (dB). This scale is logarithmic, meaning that the plot actually represents <u>ratios</u> of pairs of amplitudes. For two amplitude levels A_1 and A_2 differing by a vertical distance '*a*' dB in this plot, the amplitude ratio is

$$\frac{A_1}{A_2} = 10^{\frac{a}{20}}\,. \tag{2}$$

7) For the records from steps 3)–4), use "Processing" -> "Current Record" -> "Spectra and Export" tool in the seismograph software to look at their spectra. This tool uses the main display time window and allows selecting groups of records and time ranges for spectral analysis. **Determine the usable frequency band** in the records **at closer and farther away distances from the source**. Note spectral peaks related to resonances discussed in step 3).

8) **Repeat steps 3) and 5)–7) from one source point using different sources**:

   a. a heavier strike with the same rock,

   b. strike with a wooden peg, or strike with your fist. **Compare the records and spectra** for the different sources.

   c. "weight drop" source, which we simulate by lifting the first of the accelerometers and dropping it on the table. Note that the record of this accelerometer produces a very sharp and clean record of source impact.

   <u>GEOL 334 students</u>: **Zoom in and measure the duration Δt of this source impact**. Calculate its dominant frequency as

$$f_{\text{dom}} = \frac{1}{\Delta t} \,. \tag{3}$$

The next test introduces the so-called VibroSeis seismic recording, which is broadly used in exploration reflection seismic imaging. Compared with using explosives, this source is inexpensive and nondestructive for the surface. The idea of this method is to replace the very fast and strong impact with a broad-band signal produced by a vibrator and extended over time.

In hydrocarbon exploration or deep crustal studies, the vibrator would be an about 12-ton truck and the sweep would be from about 8 to 80 Hz (or ~140 Hz and mini truck or trailer for shallow work). Smaller and higher-frequency vibrators are used to study road pavement and for cross-well seismic imaging in boreholes (with frequencies up to ~300 Hz). In this lab, we use a loudspeaker transducer (driver) designed to play sound through tabletop surfaces in conference rooms.

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9) Again **repeat recording as in step 2), this time using a small tabletop vibrator** powered by a signal function generator. Use a 1-s long 100 Hz to 2000 Hz upsweep (signal with frequency gradually increasing with time).

10) Look at the sweep record in the time and frequency domains. **Describe in the report** how the frequency changes with time and how the bandwidth is seen in the spectra.

11) Finally, select "Cross-correlation with chan#1" in the display of sweep records. This is called the "vibroseis correlation". **Describe whether (and how closely) the records resemble the results of using impulsive forces above**. **Try measuring the moveout of the wave** traversing the accelerometer spread. **Are the moveout and wave velocity close to those measured in step 2**?

Experiment 2: Seismic event location

Data acquisition

12) **Move the 8 receivers from the table and place them along the perimeter of the room**: four stations at the corners and four stations near the middles of each wall. Plan several source points (mark them with chalk or something else). Use measuring tape to **measure the coordinates** of all receivers and source points. **Sketch the layout in your workbook** and provide the coordinates for entry in the recording computer.

13) **Use a hammer** to strike at every source point and make recordings as in the previous lab. Create **screen captures** of the records.

14) **Repeat the same source points** with another type of source. For example, stomp feet at the marked locations.

Data analysis

15) Look through the recorded records in the seismograph software. **Compare the records from hammer and "stomper" sources**. Use the spectral analysis tool ("Processing" -> "Current

Record" -> "Spectra and Export") to **compare the spectra of the sources**. **Which of these sources gives better first arrivals**?

16) Use "Processing" -> "Current Record" -> "Edit and Pick…" tool to pick the first arrivals for the selected type of sources. This tool can also be used for shifting the time origins of the records and for editing ("killing") bad records. We should not need these options though.

17) Use "Processing" -> "Current Record" -> "Locate" tool to **locate the sources for each record**.

In this class, we do not study the algorithms of location but only familiarize ourselves with the general idea (Figure 1). First arrivals are picked (red lines and crosses in the plot on the upper-right) and used to create a time-distance plot (lower-right plot) and a plot of "average misfit between the measured and predicted travel times for each source-receiver pair (color plot on the lower-left). From the time-distance plot, velocity can be measured from the slope of the travel-time curve. If the velocity turns out to be difficult to constrain, it can also be inserted manually and used for location (panel on the upper-left).

In the location plot (left), the best location is indicated by the smallest misfit (light color and green cross). Black arcuate lines in this plot also indicate source locations which would produce exactly the times observed at each of the individual receivers. Thus, the true source location must occur near the intersection of all these lines.

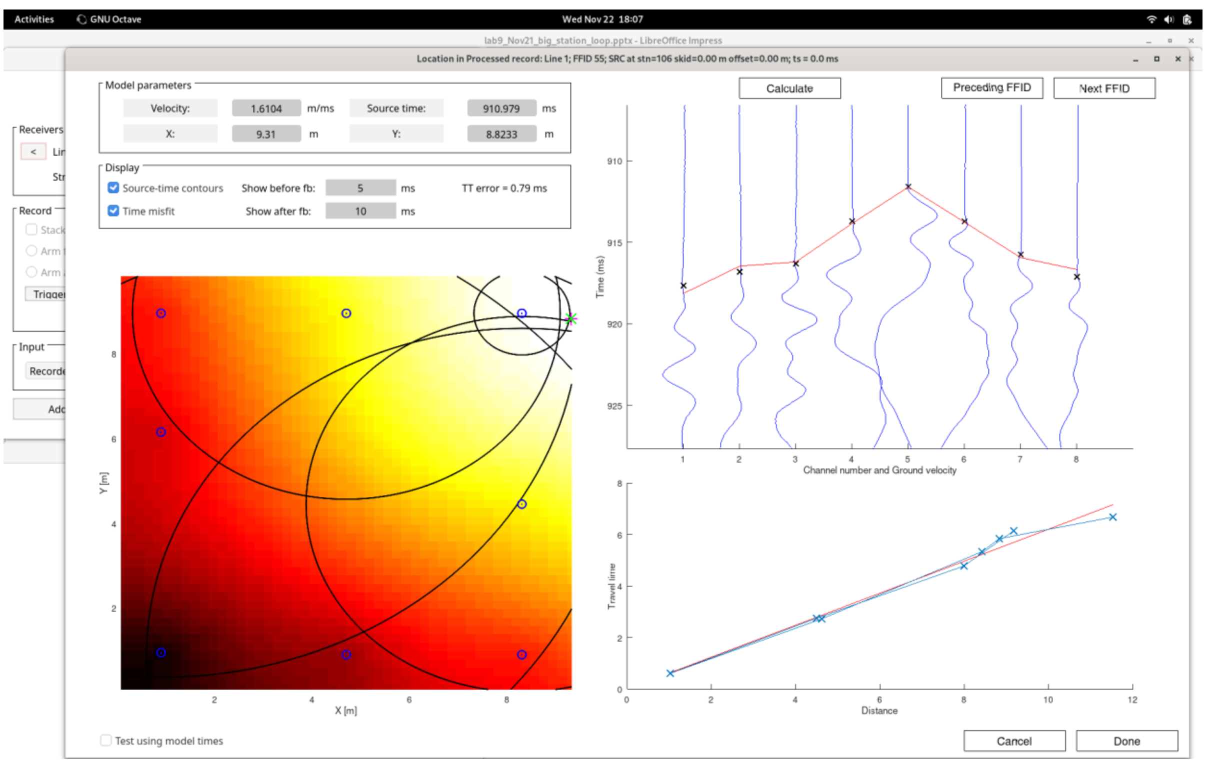

Figure 1. Sample display from the location program used in this lab.

18) Look at plots like Figure 1 for several records of this lab. How well do they correspond to the known locations? **Write down in your report the source times t_S and the estimated velocities V.** Are the values of V close when estimated from different sources?

19) **Compare location accuracy** for different sources. In which directions and in which parts of the room (center, corner) the locations are more accurate? Semi-quantitatively, this can be seen from the appearances of the images of the objective function (color in Figure 1).

Hand in:

Zipped directory, Word, or PDF document containing answers to the above questions and images.