LAB 4: SEISMIC REFRACTION

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Due: **Before** your next lab session

Overview

Estimating the thickness of geologic layers is commonly required in many earth science applications. Some examples are:

- Estimating the depth to a water table or to bedrock
- Characterizing the subsurface before laying the foundation for a new building

Common invasive techniques (drilling, cone push, etc.) provide information at points, but geophysical methods must be used to "connect the dots"; i.e., to build a more complete understanding of how layer thickness varies under a line. Seismic refraction is commonly used to obtain such information.

Resources

- GPG: https://gpg.geosci.xyz/content/seismic/basic_principles.html
- Jupyter Notebook: GPGlabs SeismicApplet.ipynb
- Jupyter Notebook: GPGlabs Seis_Refraction.ipynb

Sketch the problem

To explore seismic refraction, we start by using a simple three layer model that consists of a dry sandstone (layer 1) overlaying a saturated sandstone (layer 2) which overlays a shale (layer 3). The parameters are shown in the table below. For the survey, we position the shot point at x = 0 m, and 12 geophones with equal spacing as shown in Figure 1. In the figure, x0 indicates the offset between the shot and the first geophone, and dx is the spacing between two adjacent geophones.

	thickness (m)	**P-wave velocity (m/s)**
dry sandstone	5	400 m/s
saturated sandstone	10	1000 m/s
shale	half-space	1500 m/s

Table 1: Parameters for three layer model.

Q1. Consider the three-layer model in Figure 1. Let interface 1 denote the boundary between layer 1 and 2 and interface 2 denote the boundary between layers 2 and 3. On Figure 1, sketch and label the following:

a) A direct ray path from the shot to geophone 2
b) A reflected ray path from the shot to geophone 6
c) A critically refracted ray path from the shot to geophone 8 via interface 1
d) A critically refracted ray path from the shot to geophone 12 via interface 2

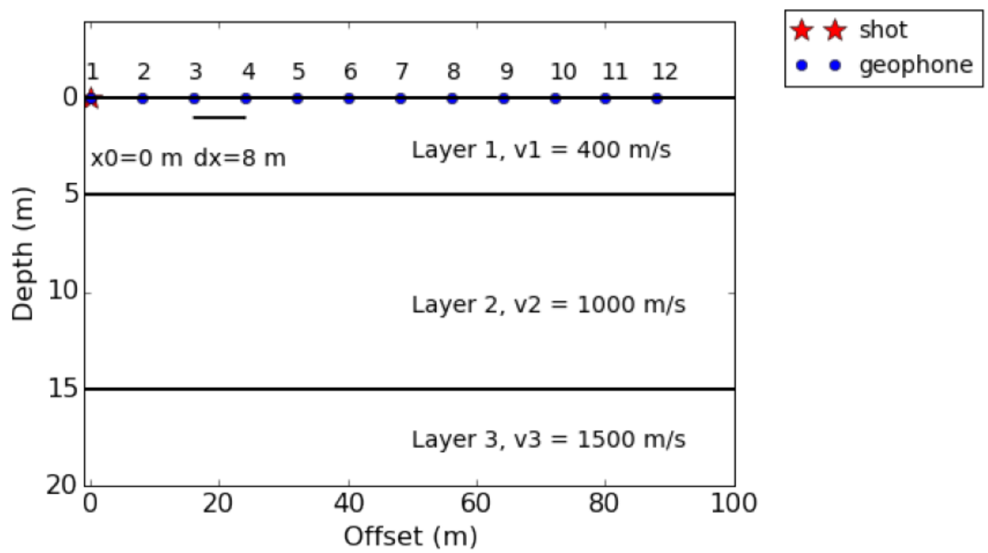

Figure 1: Conceptual diagram of seismic refraction survey with three layer model.

Travel times for different ray paths

We consider three types of rays: the direct ray, the reflected ray due to interface 1, and the critically refracted rays at interfaces 1 and 2. Relevant travel time equations for each ray are given in the GPG.

The following questions ask you to examine different characteristics of each ray. To answer them, use the velocities shown in Table 1 and the survey layout shown in Figure 1. You are encouraged to use the seismic app to build intuition and check your answers but you must use the appropriate formulas from the GPG and show your work for each answer.

Direct ray

Q2. For the third geophone (offset $x = 16$ m), when will the **direct ray** arrive?

Q3. On a T-X diagram, what is the slope of this direct ray?

Reflected ray from interface 1

Q4. For the third geophone (x = 16 m), when will the **reflected ray** arrive? Compute this and show the equation that you used.

Q5. What is the minimum time at which a reflected wave can be observed at any point on the surface? Where is it observed? Compute this and show the equation that you used.

Q6. Use the seismic app to observe the slope of the travel time curve at large offsets. Which other ray has this same velocity? By increasing the offset in the app, explain why the direct and reflected travel time curves converge. You do not need to compute the slope by hand.

Refraction: interface 1

Q7. Consider the **critically refracted ray** along interface 1. Denote the incident and refracted angles as θ_1 and θ_2, respectively. By using the definition of critical angle

(θ_c) shown in the GPG, compute the critical angle at interface 1. Compute this and show the equations that you used.

Q8. What is the distance from the source at which the first critically refracted wave arrives? Compute this and show the equation that you used.

Q9. Find the receiver offset where the first refracted ray over-takes the direct ray. Compute this and show the equation that you used. (Hint: see crossover distance in the GPG).

Q10. The critically refracted ray travels a longer distance than the direct ray. How is it possible for the refracted ray to overtake the direct ray?

Q11. Use the seismic app with default parameters and compare the crossover distance that you computed in Q9 to what is shown in the app.

Q12. On the T-X diagram, what is the slope of the critically refracted ray?

Refraction: interface 2

Now consider the critically refracted ray on the interface between layers 1 and 2 (interface 2). Use the seismic app with default parameters and equations in the GPG to answer the questions.

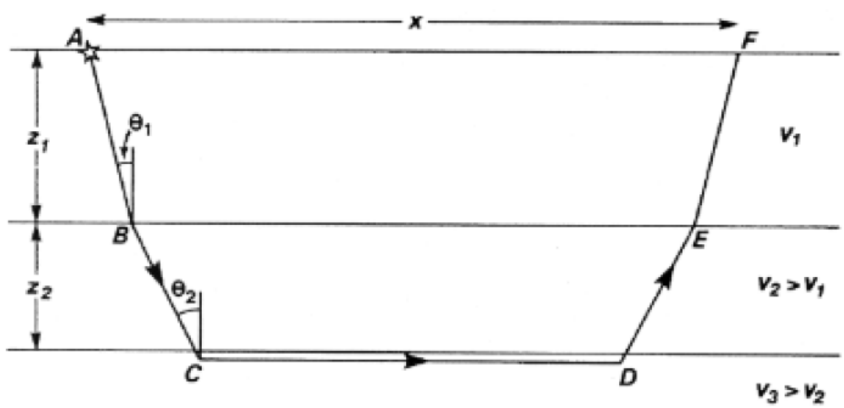

Figure 2: Conceptual diagram of critical refraction at interface 2.

Q13. Consider the diagram in Figure 2. What are the angles of incidence (θ_1 and θ_2) at interface 1 and interface 2 that are needed to have the ray critically refracted? Compute this and show the equations that you used.

Q14. At what offset is this critically refracted ray first predicted to arrive? Compute this and show the equation that you used.

Q15. Using the seismic app, at what offset does this critically refracted ray start to be recognized as a first arrival?

Q16. On the T-X diagram, what is the slope of this critically refracted ray?

Q17. Using the seismic app, determine the range of offsets for which each ray type is the first arrival

- Direct
- Refraction 1
- Refraction 2

Interpretation of seismic refraction data and acquisition strategies

In this section, we explore how to interpret seismic refraction data and investigate the impact of survey design using the python notebook **Seis_Refraction.ipynb**. This app combines text and graphics with interactive computations. Please follow the instructions given by the TA to launch the notebook on the lab computers.

Direct arrival

Q18. What is the minimum number of traces, for a given ray, that need to be recorded to determine the velocity of a layer?

Q19. Run the first 2 cells in the notebook. In the 3rd cell of the notebook, adjust the values of x0 and dx for the plots and re-run that cell to see the changes. What is a good choice for x0 and dx that would allow adequate observations of the direct arrivals?

Q20. To pick the wavelet arrival, you need to identify a certain point in the wavelet that you will consistently pick. Using the wavelet plotted at the beginning of the notebook, show the point that you would choose as first arrival and explain the reasoning for your choice.

Q21. Run the cell with then function **makeinteractTXwigglediagram.** Fit the direct arrivals and provide an optimal intercept time (t_i) and velocity (v_1).

Q22. Now set x0 = 1 and dx = 2. Can you distinguish the reflected arrival from the direct arrival? If you can, then increase x0 until you can no long distinguish them and provide that value for x0.

Refraction: interface 1

Q23. Within the same cell, find a good choice for x0 and dx so that the critically refracted rays from interface 1 are observed as first arrivals. Provide your values of x0 and dx.

Q24. Using the notebook, fit the refracted arrivals and provide an estimated t_i and v_2. Then compute h_1(thickness of the first layer). Hint: use the equation for the intercept time in the GPG.

Refraction: interface 2

Q25. Within the same cell, find a good choice for x0 and dx in order to observe the critically refracted arrivals from interface 2?

Q26. Using the notebook, fit the refracted arrivals and estimate t_i and v_3. Then compute h_2(thickness of the second layer). Hint: use the equation for the intercept time in the GPG.