Lab 4: Seismic Refraction

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DUE:

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"; ie 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: Seismic basic principles
- Seismic App (Thanks to Rowan Cockett, Michael Firmin and Seogi Kang for all of their hard work on this!)
- Lab4SeisRefrac App

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 below table. 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 outlined above. Let interface 1 denote the boundary between layers 1 and 2, and let interface 2 denote the boundary between layers 2 and 3. On the figure below sketch and label

(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

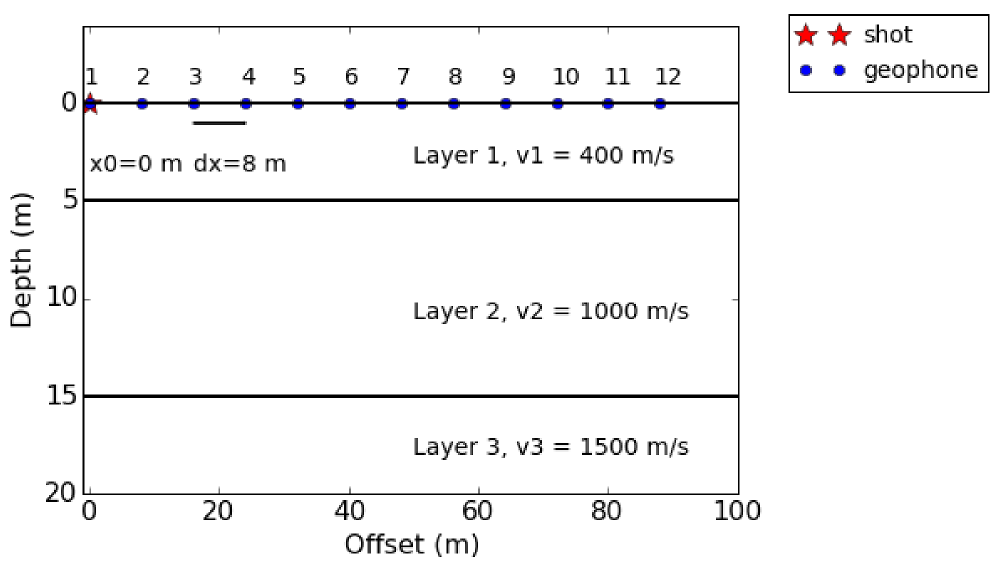


Figure 1: Conceptual diagram of seismic refraction survey with three layer model.

Travel times for different ray paths

We consider three types of rays: direct ray, reflected ray due to interface 1 and the critically refracted ray at interfaces 1 and 2. Relevant travel time equations for each ray are given in GPG: Travel times. 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're 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. (a) For the third geophone (offset, x = 16 m), when will the direct ray arrive?

(b) On the t-x diagram, what is the slope of this direct ray?

Reflected Ray from Interface 1

Q3. (a) For the third geophone (x = 16 m), when will the reflected ray arrive? (Compute this and show equation that you used)

(b) 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 equation that you used)

(c) 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

Consider the critically refracted ray along interface 1. Denote the incident and refracted angles as θ_1 and θ_2, respectively.

Q4. (a) By using the definition of critical angle (θ_c) shown in GPG: Critical refraction, compute the critical angle at inteface 1 (Compute this and show equation that you used).

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

(c) Is it a distinct arrival? Why or why not? (Check this using Seismic App)

(d) Is it a first arrival? (Check this using Seismic App)

Q5. (a) 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 ($x_{cross\ over}$) in GPG: Travel times).

(b) This ray travels a longer distance than the direct ray. How is it possible for the refracted ray to overtake the direct ray?

(c) Use Seismic App with default parameters and compare crossover distance that you computed with that shown in the app.

(d) On the t-x diagram, what is the slope of this critically refracted ray?

Refraction: Second Interface

We consider the critically refracted ray on the interface between layer 2 and 3 (interface 2).

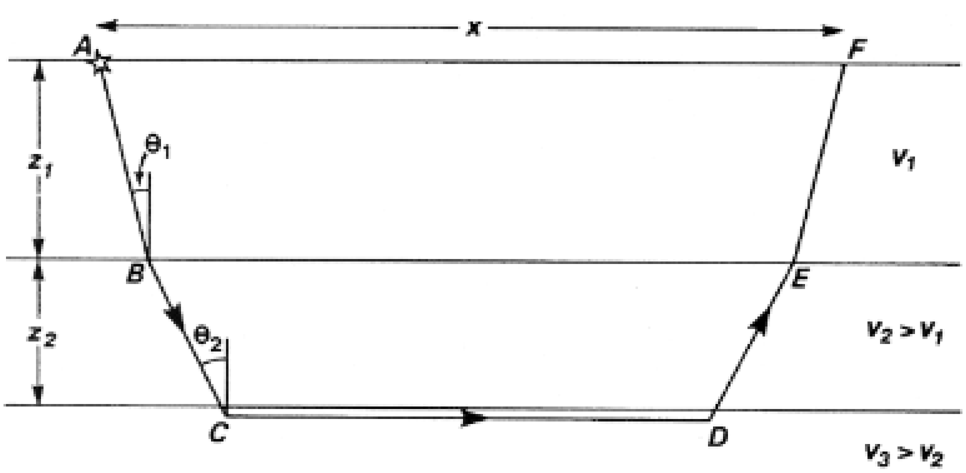


Figure 2: Conceptual diagram of critical refraction at interface 2.

Q6. Use the Seismic App with default parameters and equations in GPG: Critical refraction and GPG: Travel times to answer the following questions:

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

(b) At what offset is the critically refracted wave first predicted to arrive? (Compute this and show equation that you used).

(c) Using the app: At what offset, does this critically refracted ray at interface 2 start to be recognized as a first arrival?

(d) On t-x diagram in the app, what is the slope of this critically refracted ray? How does it compare with the expected theoretical value?

Q7. Using the Seismic App, determine the range of offsets for which each ray type (Direct, Refraction 1, Refraction 2) is the first arrival.

Interpretation of seismic refraction data and acquisition strategies

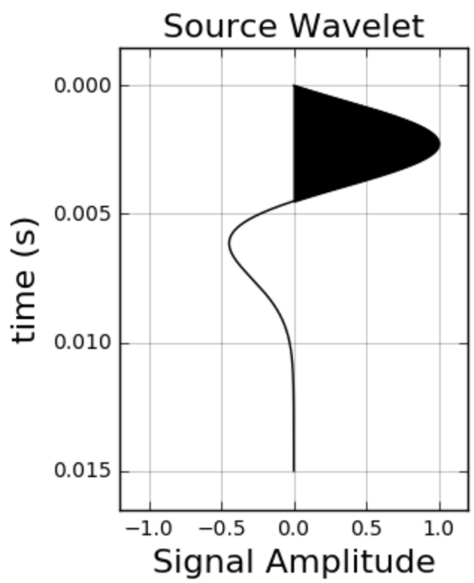
In this section, we will explore how to interpret seismic refraction data and investigate the impact of survey design using the seismic refraction survey jupyter notebook. This app combines text and graphics with interactive computations. Please follow the instructions given by the TA to launch the notebook on the lab computers. At home you can run the notebook live on the web: Lab4SeisRefrac App.

Direct arrival

Q8. (a) What is the minimum number of traces, for a given ray, that need to be recorded to determine the velocity of a layer?

(b) Using the app: What is a good choice of x0 and dx that would allow good observation of the direct arrivals? Provide below them.

(c) To pick the arrival you need to identify a certain point in the wavelet that you will consistently pick. Using the wavelet plotted here, show the first arrival point that you would choose and explain the reasoning for your choice.



(d) Using the app: Fit the direct arrivals and provide an optimal intercept time, ti, and velocity, v. What is v1?

(e) Using the app: Set x0=1, dx=2. Can you distinguish the reflected arrival from the direct arrival? If you can, then increase the x0 until you can no longer distinguish them; provide that value of x0.

Refraction: interface 1

Q9. (a) Using the app: Find a good choice for x0 and dx so that the critically refracted rays from interface 1 are observed as first arrivals. Provide their values below.

(b) Using the app: Fit these refracted arrivals and provide an estimated ti and v. What is v2 and z1, the thickness of the first layer? (Hint: use equation for the intercept time shown in GPG: Travel times)

Refraction: interface2

Q10. (a) Using the app: What is a good choice for x0 and dx in order to observe the critically refracted arrivals from interface 2; provide below them.

(b) Using the app: Fit the refracted arrivals and estimate ti and v. What are v3 and z2 (Hint: use equation for the intercept time shown in GPG: Travel times)

Survey design

Q11. (a) Your object for seismic refraction survey is to design a single survey so that information from all three layers can be obtained. What x0 and dx would you use. Justify your answer.