Lab #8. Spatial Resolution

In Lab #4, we utilized seismic modeling to understand different types of waves. Here, we will apply seismic modeling to understand spatial resolution.

Generally, two points are considered unresolvable when their two-way reflection times are separated by less than half of the dominant period of the signal (T):

$$\delta t < T/2. \tag{1}$$

In this lab, you will simulate two experiments and measure the effects of the wavelength on spatial resolution (Figure 1). In both experiments, the modeling area covers 1500 m horizontally. Collocated sources and receivers are distributed along the top of the model at 10-m intervals (stars in Figure 1). The time sampling interval is 1 ms.

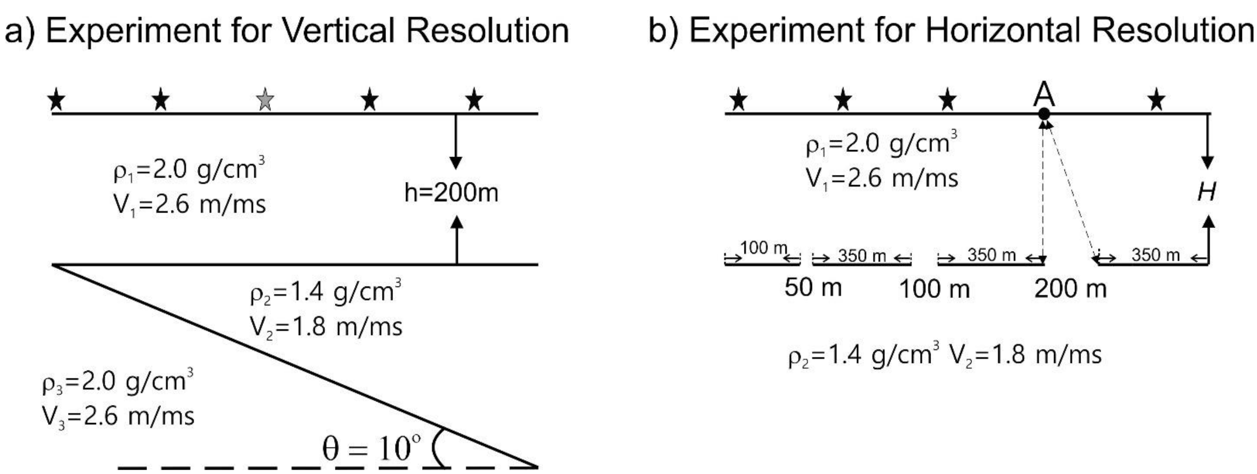

Figure 1. Experiments illustrating: a) vertical seismic resolution, and b) horizontal resolution.

a) Vertical Resolution

Vertical resolution is the ability to separate reflections in vertical direction. Generally, the vertical separation of resolvable reflections δz can be derived from (1) as

$$\delta z = \frac{\lambda}{4} \ , \tag{2}$$

where λ is the wavelength. To illustrate this relation between λ and δz, consider reflections from the top and bottom of the wedge structure shown in Figure 1a. Because of the varying thickness of the wedge, its top and bottom are resolvable over the right side of the wedge and unresolvable on the left. Your task will be to identify the location separating these two zones (schematically shown by the grey star in Figure 1a).

b) Horizontal resolution

Horizontal resolution measures our ability to separate reflecting points laterally. From the same criterion (1), the minimal horizontal separation between resolvable reflectors equals

$$\delta x = \sqrt{\frac{1}{2} H \lambda} \, , \qquad (3)$$

where H is the depth. The experiment for horizontal resolution is shown in Figure 1b. The depth H of the reflector will be 200 m, 700 m or 1400 m in order to investigate the effect of H. The widths of the gaps are as shown in Figure 1b. The reflectivity for these gaps are zero, which means no reflections will come from these gaps.

Note that for the sources and receivers located above an edge of the gap (for example, point A in Figure 1b), reflection from the other edge of the gap will be recorded as well. The gap will be considered unresolvable if the two reflections from the two sides of the gap look like a single reflection at point A.

Things to do

- **Experiment a)**

  1) Model the zero-offset reflections with a 30-Hz wavelet by using Matlab functions from lab #4 and the new scripts `reflection_VI.m` ("reflection at vertical incidence") and `experimentA.m`. (15%)

     Look into both of the new scripts and understand their logic. Note the calculation of mean velocities above boundaries by harmonic means (averaging quantities $\Delta z/V$, which are the travel times within layers). Also note the calculation of reflection coefficients from impedance formulas.

Do waveform polarities in the plot look correct? Are they in agreement with the model in Figure a) above?

2) Identify the traces with a single peak or double peaks below the horizontal reflector. Note that the reflection from the bottom (sloping) surface of the wedge have opposite polarities, and so the reflection from the top gives a positive peak, and reflection from the bottom is a negative-polarity peak. Identify the rightmost position where the two peaks still cannot be recognized. Measure the thickness of the wedge at this location. How does it relate to δz in formula (2)? (25%)
3) Try to model the reflection received from the identified rightmost position in step 2) but change the dominant frequency to 60 Hz for the input source wavelet. Use script `make_wavelet.m` from lab #4 to precompute the 60-Hz wavelet.

   In this case, can these two peaks be distinguished? Why? (5%)

- **Experiment b)**

1) If the wavelet frequency has been changed in experiment A, restore it to 30 Hz by using `make_wavelet.m`.

   After that, make sure that `depth` is set equal $H = 200$ m at the beginning of script `experimentB.m`. Go through this script and understand how it models zero-offset reflections from a reflector with gaps.

   For each source/receiver location on the surface, the script first calculates the reflection from the horizontal reflector beneath it, and then from each of the edges of the gaps. Note how the modeling time range (array `time`) is set so that it changes automatically when `depth` or velocity is varied. Note that the model reflectors (Figure b) above) are plotted <u>in the seismic time section</u> by red lines. This is the so-called 1:1 time-depth scaling mentioned in the lectures and homework assignments.

Execute the script `experimentB.m`. Do you expect positive- or negative polarity reflection from layering in Figure b)? Do you see such polarity in the records? (10%)

2) Compare the seismograms at the edges of each of the three gaps. Identify those where you can differentiate between the reflections from the two sides of the gap. (10%)

3) With $H = 200$ m, model zero-offset reflections by using wavelet with dominant frequency equal 10 Hz, and 60 Hz. Use script `make_wavelet.m` from lab #4 (a copy given in this lab) to precompute these wavelets.

   At which dominant frequency does the seismogram have a higher horizontal resolution? Is this as expected? Explain why. (15%)

4) Perform two more simulations with H = 700 m and 1400 m using the 30-Hz wavelet. Compare the obtained reflections. How does the horizontal resolution change with H? (20%)