Lab #10. Multichannel Analysis of Surface Waves and passive noise recording in classroom

Compared to the previous labs, here, we will try two completely different approaches to seismic imaging:

1) Multichannel Analysis of Surface Waves (MASW), and
2) Passive seismic imaging using microtremor noise.

Both of these methods are broadly used for shallow seismic studies, and they are particularly useful in urban environments. In this lab, we will collect seismic data on the floor of room Geology 265.

The MASW method

The MASW method measures the velocities of surface waves, which are most sensitive to the variations of S-wave velocities within the layered shallow subsurface. Thus, MASW is a unique tool for measuring the shallow S-wave velocities, and they are very difficult to assess by other methods. Shallow S-wave velocities are useful in several applications:

- As complementary data for first-arrival refraction (P-wave) imaging. By knowing both P- and S-wave velocities, rock types and their physical conditions (e.g., presence of fluids) can be constrained much better.
- Using relation $V_S = \sqrt{\mu/\rho}$ and some estimate for density ρ, S-wave velocities can be transformed into variations of the weak-deformation shear modulus (i.e., $\mu = \rho V_S^2$). This application of MASW is very popular in engineering seismics, giving a direct estimate of the mechanical strength of the subsurface.

Figure 1 shows examples of MASW images from our Geophysics field school in 2021. In this lab, we will use only one position of the line on the floor, and therefore our goal will only be to produce a surface-wave velocity dispersion image similar to Figure 1a.

The MASW method consists in using a dense line of geophones (we will use accelerometers), conducting hammer strikes a little off-end with the line, and recording surface waves traveling through the line. From the Nyquist criterion, with sensor spacing Δx, we should be able to record (analiased) waves of wavelengths $\lambda > 2\Delta x$. For surface waves, the depth of their penetration into the ground is roughly half of the wavelength, and hence the quantity $\lambda/2$ is often called the pseudodepth. Therefore, with sensor spacing Δx, we should achieve depth sampling to about $z_{\min} \approx \frac{\lambda}{2} \approx \Delta x$. Similarly, if the total length of the line is L, then the maximum depth of the sampled structure (like shown in Figure 1b) is approximately $z_{\max} \approx L$.

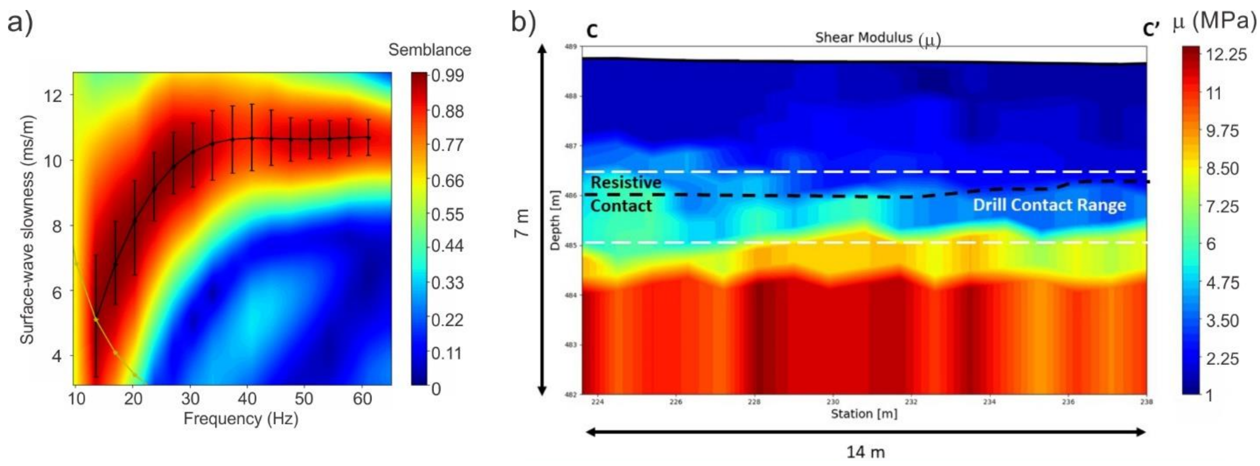

Figure 1. MASW image of an area of landslide beneath the trail along the eastern riverbank (near Saskatchewan Crescent and 16th street; 2021 UofS field school): a) dependence of the surface-wave slowness on frequency; b) inverted distribution of the shear modulus μ with depth and distance along the line. Data analysis and images by Mark Lepitzki).

The principle of MASW data analysis consists in measuring the dependence of surface-wave velocity on frequency (Figure 1a). This dependence is measured by transforming the data into the frequency domain using fast Fourier transforms and performing multiple trials for velocity values, similar to the stacking-velocity analysis of reflection records in the previous labs. Note that in Figure 1a, the frequency-dependent *slowness* $1/V_S$ of the wave is shown on the vertical axis instead of velocity V_S.

The key observations which we need to establish from the dispersion-semblance plot (like Figure 1a) are 1) what is the level of wave velocity at high frequencies, and 2) whether velocity dispersion is present, i.e. whether the velocity varies with frequency. Cases of velocity $V(f)$ decreasing with frequency (slowness $1/V(f)$ increasing, like in Figure 1a) are called normal dispersion, and the opposite case is called anomalous, or inverse dispersion.

Normal dispersion is commonly seen for surface waves at all scales, and we also may expect to see it in this lab. Normal dispersion is caused by S-wave velocity increasing with depth. Lower-frequency waves are longer, and therefore they penetrate deeper and are affected by the faster layers. Consequently, low-frequency waves are typically faster, and their velocities can be used to estimate layer velocities.

However, when working within the building, we should not be surprised to find anomalous dispersion (velocity decreasing with increasing frequency). Such dispersion is characteristic of flexural deformation of a thin plate. The floor in the classroom may likely exhibit such flexural modes.

The passive-source Noise-Correlation method

In the second method, the goal is also to measure the velocity of the medium (maybe even velocity dispersion) but by using ambient vibrations (microtremors) as the source. Ambient higher-frequency tremors are constantly present in urban areas, and particularly within buildings. Microtremors consist of waves traveling in random directions across the study area. The idea of the method consists in "passive" recording long time intervals of microtremor "noise" and using data processing to enhance waves traveling along the receiver spread.

The noise-record data processing consists of the following steps:

1) Normalizing the amplitudes of the records so that strong events do not have preference over the weaker ones. It is thought that clear and stronger, coherent arrivals should actually be avoided (muted out) in the records, so that they do not bias the noise correlations.
2) Selection of some receiver (for example, #1) as reference and cross-correlation of each long of the other records with it. The cross-correlation peaks will look like a wave traveling from the reference receiver. Thus, the reference receiver effectively becomes the seismic source in the cross-correlated section.
3) From the travel-time moveout of the peaks in the cross-correlated section, seismic wave velocity is determined. Sometimes, the dependence of velocity on frequency (velocity dispersion) can also be detected by using band-pass filtering before cross-correlation.

In this lab, we will not be able to record very long time records and will use a "cheated" (accelerated) version of acquisition and step 1). However, it should still clearly illustrate the microtremor correlation idea. During recording, we will add "noise" by striking floor near the inline direction of the receiver spread. This should add microtremors which should cross-correlate effectively and contribute to forming the effective sources at the reference geophones.

Things to do

We will conduct two seismic location experiments in classroom 265: one with eight stations located around the perimeter of the room, and one with a smaller loop of stations placed around the center of the room.

Data acquisition

Data acquisition in this lab is very easy:

1) **Place the 8 receivers in a line with about 30 cm spacing**. Use measuring tape to **measure the coordinates** of the receivers and two source points (in-line) on each side of the line.
2) Using wave velocities measured in the preceding lab, **estimate the wavelength** which you expect to obtain at source frequency of 2 kHz. **What depth range** will the selected receiver spacing allow imaging?

You will likely find that the waves at 2 kHz are still too long to detect any layering within the floor.

3) **Use a hammer** to strike at the source points and make recordings as in the previous labs. Create **screen captures** of the records.
4) **Repeat the same source points** with vibrator source. Use 100-2000 Hz upsweep with 10-sec duration. This test should be recorded in a different project in the computer, so that changing the duration of the records does not complicate visualization and data analysis.

Data analysis

5) For each of the MASW shots, use the spectral analysis tool ("Processing" -> "Current Record" -> "MASW Dispersion Analysis"). Include the vibrator sources if possible. C**ompare the semblance spectra to the one in Figure 1a**. **Do you see normal or anomalous velocity dispersion**?

From the question in step 2), you will likely see that our frequencies may not reach the high-frequency plateau $V(f) \approx$ const illustrated Figure 1a. C**omment on whether this is true** or not.

6) For all noise records together, use the spectral analysis tool ("Processing" -> "All Record" -> "Cross-correlation and Deconvolution"). **Can you recognize "waves" traveling from the reference receiver** in the cross-correlated records? **What is the wave velocity** of these waves?

7)

Hand in:

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