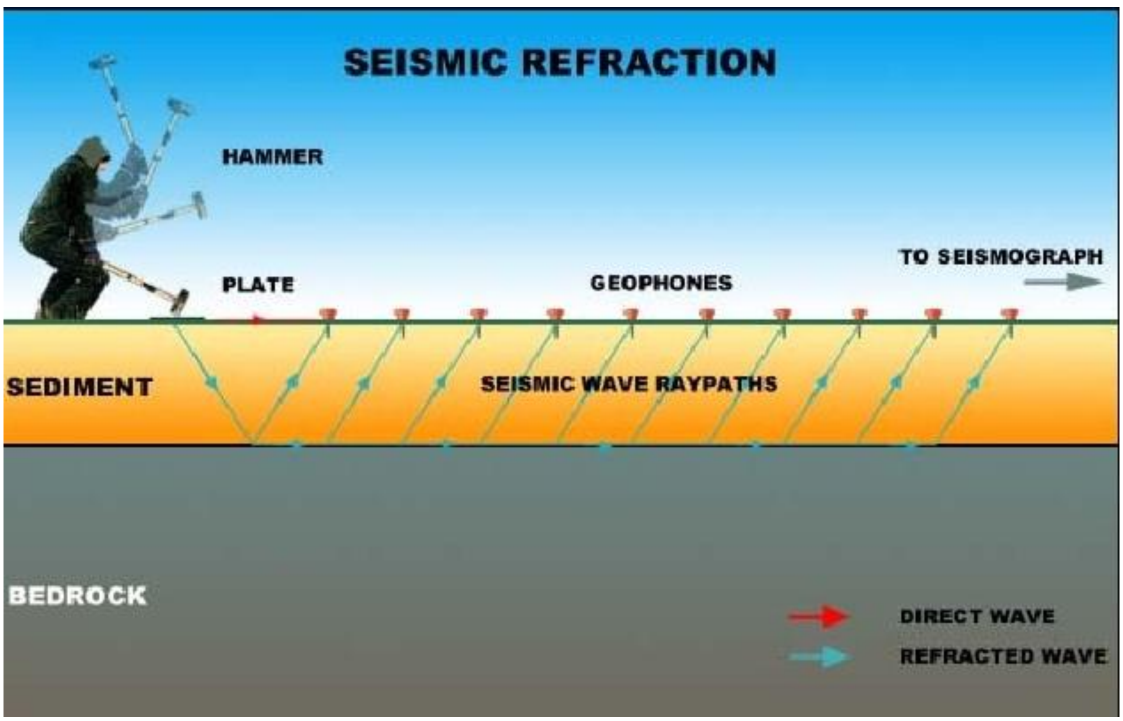
Technical Description of the Seismic Refraction Method for Geophysical Exploration using a StrataVisor



Introduction

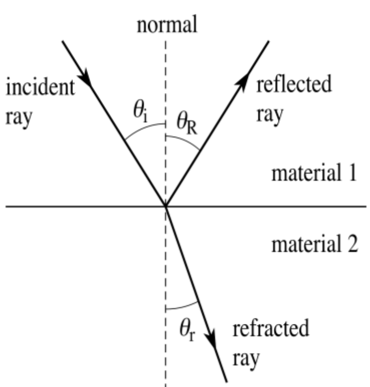
Definition

A refractive seismic survey is a geophysical technique that uses Snell's Law of Refraction and Huygens's Principle of Wave-Front Motion to measure observable differences in the speed of seismic waves within mediums under the Earth's surface. The refractive seismic method is commonly used in geotechnical engineering and geophysical studies, and it is the most frequently used technique for shallow subsurface investigations. These investigations have many purposes, such as determining bedrock depth for construction purposes, identifying fault locations, finding the depths to underground water sources, and exploring reservoirs for water and oil. The technique is performed using a spread of geophones placed on the surface of the ground, a seismic energy source, and the creation of a seismogram.

Geophysics

Geophysics works to characterize the subsurface quantitatively and qualitatively by comparing it with other physical parameters that our eyes can detect. Geophysical techniques visualize structures hidden below the Earth's surface that are unperceivable to the human eye. Seismic exploration aims to illustrate the subsurface using differences in acoustic impedance: the product of a material's density and seismic wave velocity. The acoustic impedance varies when frequencies are changed; at a particular frequency, it indicates how much sound pressure is generated by an air vibration.

Seismic Refraction



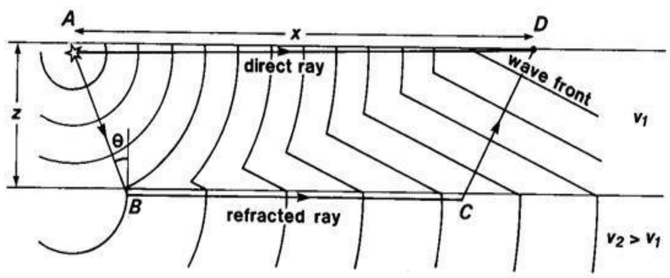
$i_c = \sin^{-1}(v_1/v_2)$

To understand seismic refraction, consider a more familiar case: the process of a pebble impacting a body of water. When the pebble hits the water, a sudden change in position of the water spreads outward until it arrives at a point where the motion recognizes it.

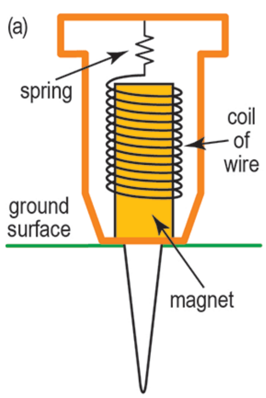
The same principle applies in seismic refraction. The goal is to measure travel time for a refracted ray transmitted along an interface by recording the earliest times of arrival of the seismic waves at various distances from the source. To accomplish this, you need to know the speed of the ray and the ray's path through the subsurface. Snell's Law provides the mathematical framework used for developing the ray path of the wave, also known as the head wave.

The initial transmission direction of the seismic wave is known as the angle of incidence. When the seismic wave reaches a certain value, the refracted ray travels along the boundary with an angle of refraction of 90-degrees. This is known as the critical angle and is also the largest angle of incidence at which refraction can still occur. At the critical angle, I_c, the transmitted ray travels parallel along the interface. The head wave travels downward towards the interface at the critical angle at a speed of v_1, spreads horizontally along the interface at a speed of v_2, and then transmits back up through the layer at the critical angle at a speed of v_1.

Before the head wave can be recorded at the Earth's surface, it travels along the bottom of the layer at a faster speed than the direct wave. This indicates that v_2 is sufficiently larger than v_1. Therefore, v_2 can be recorded prior to the time of arrival of the direct wave after reaching a certain distance.



The Geophone



A geophone converts ground motion into a recordable voltage. Geophones are composed of a magnet and spring suspended within a coil of wire. When the ground moves at the geophone's location, it creates movement between the magnet and the spring and the stationary wire coil fitted to the housing. This speed creates an *emf* voltage. This voltage is proportional to the velocity of the coil in the magnetic field.

Several challenges must be considered when using a geophone. For instance, you need enough motion to trigger movement back and forth in the spring, so geophones should be sensitive enough to suit the purpose of a survey. Additionally, most natural systems tend to create sound when moving back and forth at their natural frequencies. If this happens in the geophone, it produces incorrect data, so it is important to prevent the geophones from creating sound.

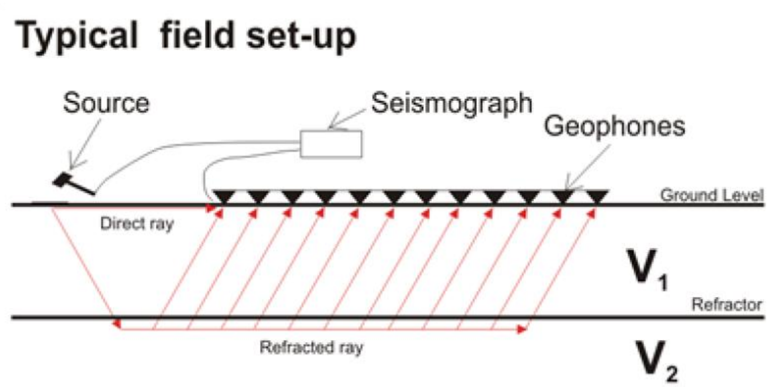
Discussion

Step 1: Placing the Geophone Array

Equipment Needed:

- Geophones
- Seismic cable(s) with connector terminals
- Measuring tape (100 meters or larger)
- Plastic carrying bin
- StrataVisor

A seismic array consists of a series of geophones connected through a cable that runs the length of the entire spread. Each geophone contains two terminals (one positive and one negative) that must be attached to their respective connectors of the cable. Cables typically have geophone terminals spaced every 3-5 meters, but it varies depending on the spread.



First, you determine a separation distance between geophones and use measuring tape to position the geophones appropriately. Then, you place the geophone cable along the entire length of the spread so you can connect the terminals. Geophones are spread in multiples of 12 (i.e. 12, 24, 48, etcetera). The total spread of the geophone series is typically 5 times the depth you want to investigate during the seismic sampling. Typical depths range from 5-50 meters deep.

The depth of investigation depends on the spread of geophones and the source that creates the waves. The farther down you want to investigate, the larger the spread of geophones and sources must be, and vice versa. Once the geophones have been placed, you can connect the geophone cable to the StrataVisor: a seismic system that allows data collection in all environments. It is important to avoid getting any dirt or mud on the connecting terminal of the cable to ensure a strong connection. When you connect to the StrataVisor, the individual geophone channels will be marked and their locations relative to their placement on the cable will display on the screen. The StrataVisor unit can handle up to 64 different geophone channels at once. Once the geophones are installed and all channels are recorded properly, you can begin sampling the subsurface.

Step 2: Creating a Seismic Signal

Equipment Needed:

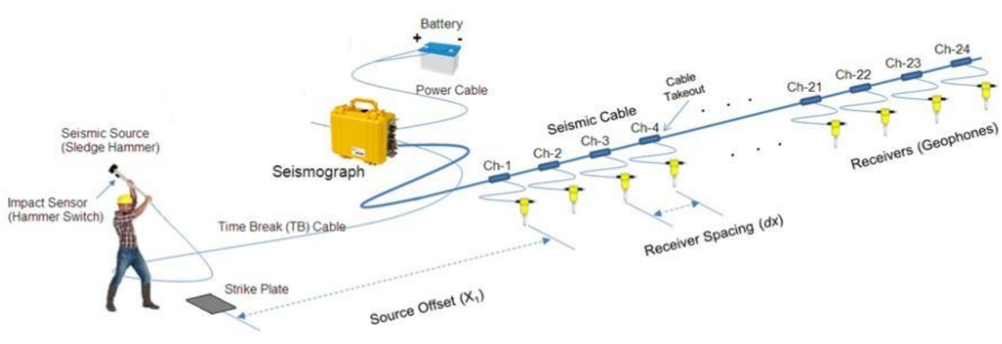
- Sledgehammer (or Vibroseis truck, explosives)
- Impact sensor (hammer switch)
- Time-break cable
- Striker plate
- Hearing protection
- Crew (at least 2 people)

The geophone array described in step 1 acts as a receiving line for a system of seismic sources. The receiving points will record the refracted vibrations from source points. The source lines should be laid out parallel to the geophone spread to produce a 2-dimensional image of the subsurface and its structures. The spacing of the source points depend on the objectives of the survey. The point separation typically ranges from 10-100 meters apart.

The seismic energy source for a near-surface survey is typically an impact from a sledge hammer. However, if deeper exploration is required, either a Vibroseis truck or an explosive charge (typically a Primacord) may be used. The source will also depend on other site-specific factors, such as rock-type and financial constraints. When a sledgehammer strikes a strike plate, it can produce a wave up to 20 meters into the ground, which is a depth more than sufficient for most engineering purposes. Sourcing a seismic signal through the ground will require at least two people because one person needs to source the signal while another person monitors the display.

The process begins by placing the strike plate on the ground in the center of the array of geophones. Then, you strike the plate with the sledgehammer and begin collecting data. The StrataVisor employs a stacking correction technology that layers signals to build them up and amplify the result. However, the StrataVisor will only process incoming signals about every 2 seconds, so the hammer strikes need to be timed accordingly.

Configuration of 24-Channel Seismic Acquisition System



Step 3: Using the StrataVisor for Processing and Interpreting Data

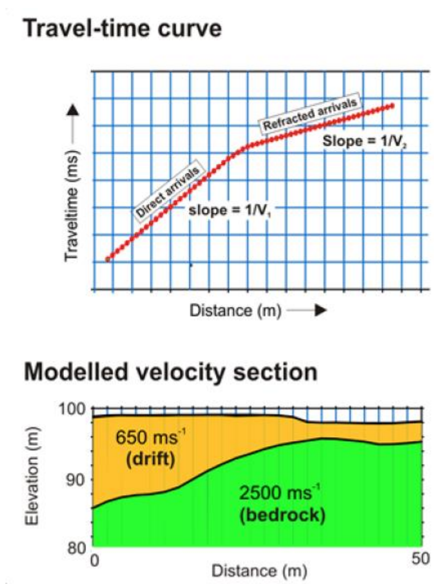
Equipment Needed:

- StrataVisor seismograph
- 12V battery
- Digital cables

The StrataVisor records and collects data from a seismic signal and composes a record of the arrival times for the seismic waves. This record is then used for interpreting differences in velocity above and below the interface, as well as the depth to the interface. The StrataVisor is an all-in-one machine that produces all the necessary graphs used for interpretation and even comes equipped with a printer. In step 2, the plate was struck multiple times so that the signals would stack. This idea is key in understanding the seismic refraction process.

The biggest challenge facing the method is noise interference from things like local traffic, footsteps, or a local gun range. For this reason, seismologists perform an operation known as signal stacking: the act of layering subsequent seismic signals. If signal noise is inherently random, then summing random signals should produce a net signal of zero. However, when the signal is intentionally produced every 2 seconds, then the signal will build constructively and the seismogram resolution will improve.

Constructing a Travel-Time Curve from a Field Seismogram



After stacking the consecutive seismic signals, the seismograph displays a seismogram that should look something like the pictures on the right. The StrataVisor depicts the seismic wave arrivals along the vertical axis in milliseconds and displays the geophone channels on the horizontal axis. While the StrataVisor will display seismic velocity and layer depth automatically, interpreting the visuals without a computer is very simple. If done correctly, the seismogram will depict a line with a changing slope. The initial slope indicates the velocity of the first layer, and the point at which the slope changes indicates a “crossover distance” for which the refracted wave surpasses the arrival of the direct wave. The slope is the inverse of the velocity being depicted in [ms/m], so by taking 1/slope and multiplying by 1,000, the result is the velocity in meters/second. This refracted wave carries information about the velocity below the interface, and it is used to derive the physical parameters using simple algebra.

Conclusion

A refractive seismic survey is a geophysical technique that measures detectable contrasts in the speed of seismic waves within subsurface mediums using Snell's Law of Refraction and Huygens's Principle of wave-front motion. There are three basic steps to completing a refractive seismic survey: placing the geophone array, creating a seismic signal, and using a StrataVisor for collecting and interpreting data. There are many benefits to conducting refractive seismic surveys, such as: finding the depths to underground water sources, identifying fault locations, determining bedrock depth for construction purposes, and exploring reservoirs for oil and natural gas. The data collected from refractive seismic surveys offers us many insights for opportunities for advancement in some of our most important industries.

Works Cited

Burger, H. Robert, et al. *Introduction to Applied Geophysics: Exploring the Shallow Subsurface.* W.W. Norton & Co., 2006.

LLC, Newline Creations. "Seismic Refraction." *Seismic Refraction | Geometrics.com,* www.geometrics.com/applications/frequently-asked-questions/seismic-refraction/.

Illustrations

http://www.met.reading.ac.uk/pplato2/h-flap/phys6_2f_7.png

https://www.ucl.ac.uk/EarthSci/people/lidunka/GEOL2014/Geophysics4%20-%20Seismic%20waves/SEISMOLOGY%20.htm

https://www.google.com/search?rlz=1C1JZAP_enUS706US706&biw=1536&bih=722&tbm=isch&sa=1&ei=ktuwXOX4Es-AtgXG-bOwAQ&q=geophone+diagram&oq=geophone+dia&gs_l=img.1.0.0.3684.5334..6887...0.0..0.101.392.3j1......1....1..gws-wiz-img.......0i8i30j0i24.bInH_Gx_M0Q#imgrc=PQc8Pha_wBzWmM:

https://www.terradat.co.uk/survey-methods/seismic-refraction/