Seismic refraction surveying

Principles of operation

The velocity of sound travelling through the sub-surface varies with material composition and compaction. Seismic energy transmitted from a source at the surface will undergo refraction at boundaries between different media and eventually return to the surface. Seismic refraction surveying makes use of this phenomenon to determine ground structure by observing the time taken for energy to travel through the subsurface. More information about seismic methods is given by Reynolds (2011).

Seismic refraction surveying requires three components: a seismic source to generate the signal, a signal-enhancement seismograph to control the survey and record the data, and a series of geophones to detect the arrival of seismic waves at multiple points on the ground surface (Figure 1). The source used for shallow surveys is typically a sledgehammer or Buffalo Gun. Note that for convenience, the passage of seismic energy through the ground is usually represented as raypaths, although the energy is actually travelling as waves. There are three paths to consider: (a) direct rays that travel from the source to the geophones along the ground surface; (b) rays reflected from sub-horizontal interfaces at depth; (c) rays that undergo critical refraction at buried interfaces and travel along these interfaces before refraction back into the overlying layer, toward the surface (Figure 1).

The time elapsed between source activation and signal detection at the receiver array is recorded on a digital seismograph. Plotting this time against source and receiver position results in a time-offset (*T*-*X*) plot (Figure 2). This typically comprises several straight line sections that can be interpreted to provide information on the seismic velocity and geological structure of the ground. The earliest arrivals (always commencing at zero travel time and zero offset) represent the direct wave. A linear decrease in line gradient represents a critical refraction of energy from the top of a faster velocity buried layer. Line gradient is the direct inverse of the layer's *apparent velocity.* The *true velocity* is determined by reversing the source-receiver array and analysing results from both the forward and reverse directions to determine the geological dip of the interface within the plane of section. The analysis procedures involved can be extended up to four layers. Not all geological situations encountered can be approximated by linear models; more detailed studies utilise either Palmer's Generalised Reciprocal Method (GRM) or one of several specialist computer packages.

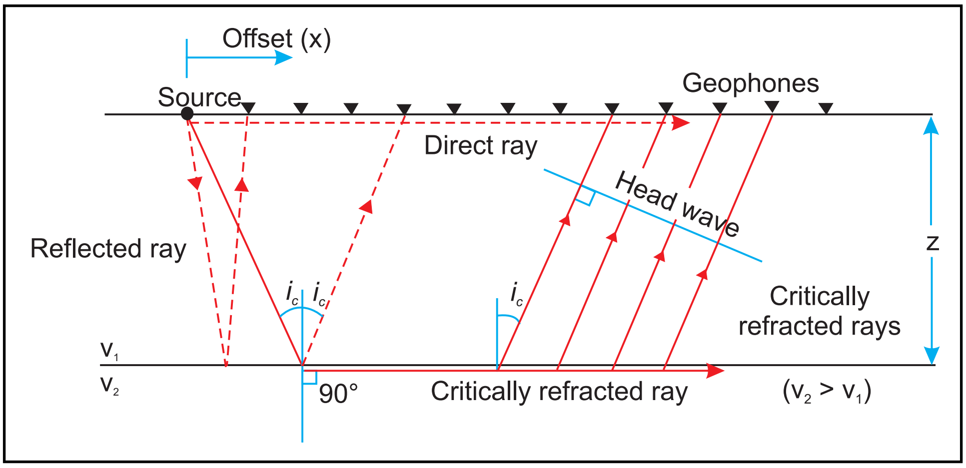

Figure 1: Raypath diagram showing the respective paths for direct, reflected, and refracted rays.

Applications

The most common application of the seismic refraction technique is to resolve variability in the depth to the top of a refractor (*e.g.* bedrock) and the seismic velocity within it. However, the method can also be used to determine rippability of materials for excavation, the degree of weathering within the top of bedrock, rock strength, thickness of saturated aquifers, location of weathered fault zones, *etc*.

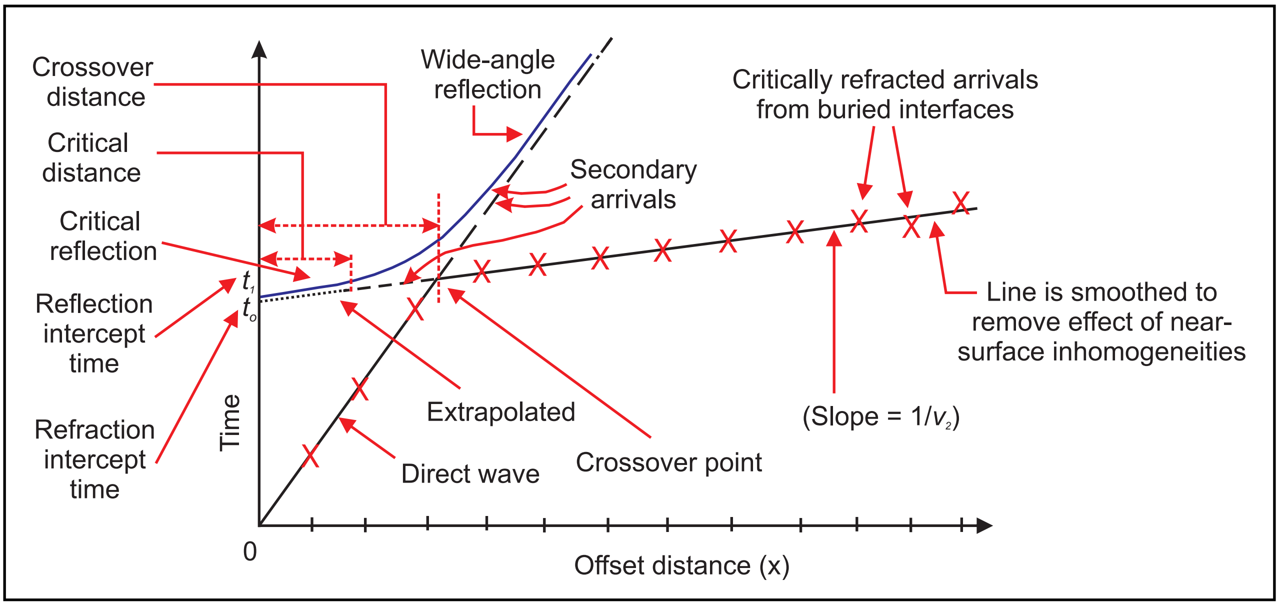

Figure 2: Arrival times plotted on a 'time-offset' (T-X) graph.

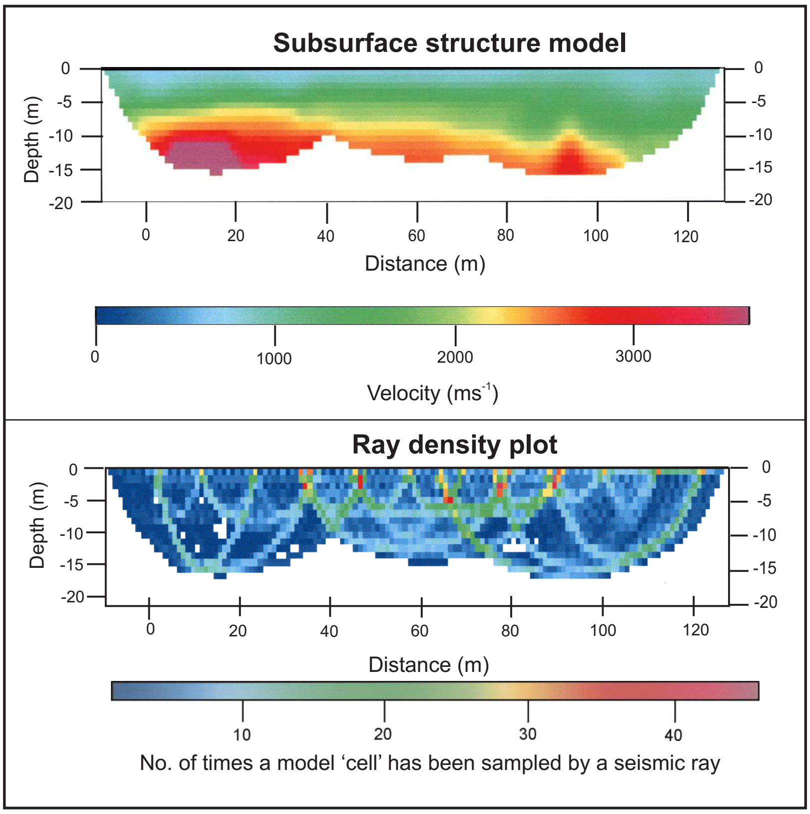

Figure 3: Example of ray-tracing iterative velocity determination using SeisOpt-2D inversion software. *Top*: Velocity structure resulting from inversion of first-arrival data using Optim Software's SeisOpt2d. *Bottom*: Raypath density plot for shallow seismic refraction model, used to assess quality of the velocity structure model.

Reference

Reynolds, J.M. 2011. *An Introduction to Applied and Environmental Geophysics*. John Wiley & Sons Ltd, Chichester, 2nd ed.,712 pp.