Chapter 2. Basic Concepts from Reflection Seismology

Introduction

In this chapter we shall present some of the basic concepts and techniques that are used in reflection seismic exploration. We shall also introduce terminology that will be used in later chapters. We shall mainly be concerned with field recording geometries, data display coordinates and simple velocity estimation techniques.

Velocity Estimation

Consider the experiment shown in Figure 2-1. A single source, s, generates acoustic waves which reflect at the interface and are recorded at the receivers, g (geophone). The recorded seismograms are plotted at the right as a function of shot-receiver offset, $(g-s)$. We define this recording geometry as the profile geometry. The data display will be termed a profile. The arrival times of profile reflections follow the well known hyperbolic trajectories given by

$$t^2(g-s) = t^2(0) + \frac{(g-s)^2}{v^2} \qquad (2\text{-}1)$$

where $t(0)$ is the two way vertical travel time and v is the velocity of the medium above the reflector. Since there are many arrival times and only two unknowns ($t(0)$ and v), these profile data can be used to determine the seismic velocity in the medium above the reflector. The profile is the simplest type of experiment which can be made to determine velocity.

Unfortunately, because profile arrival times are strongly dependent on reflector dip and curvature, velocity estimates from profiles are unreliable. The effects of reflector dip can be reduced somewhat, if estimates are made from data recorded in the geometry shown in the left frame of Figure 2-2. Notice that unlike the profile, the geometry in

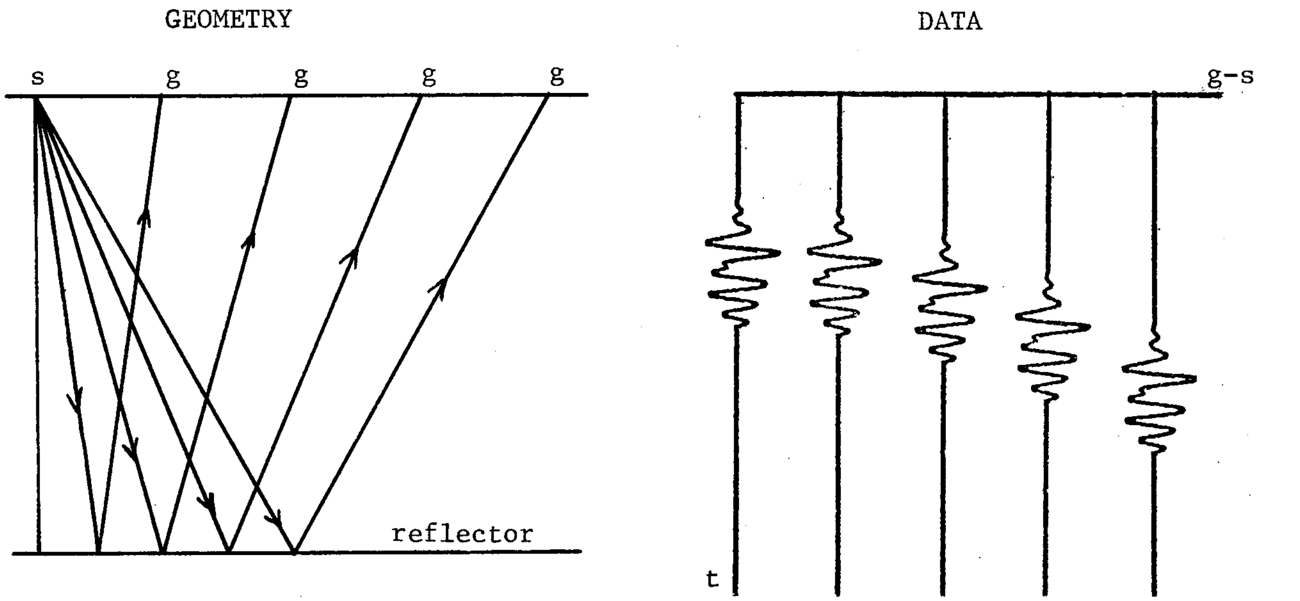

Figure 2-1. The profile recording geometry. The arrival times of the reflections are shown at the right. The data display is called a profile.

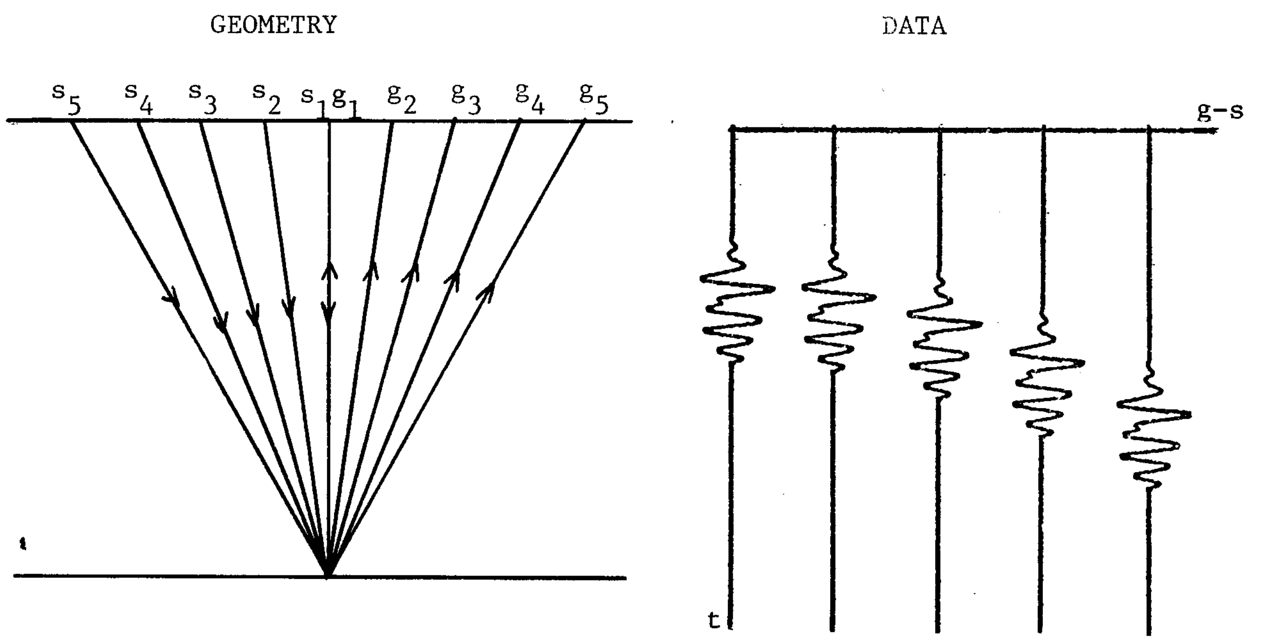

Figure 2-2. Common midpoint gather geometry and data.

Figure 2-2 has many shots and many receivers. Notice also that each shot-receiver pair has the same midpoint, $\frac{(g+s)}{2}$. The seismograms recorded in this geometry are plotted at the right as a function of shot receiver offset. We shall term this type of display a <u>common midpoint (CMP) gather</u>. Often this data display is called a common depth point gather. We shall not use that terminology here, because such data have a common depth (reflection) point only if the reflectors are plane layered. The arrival times of the CMP gather data are also given by equation (2-1). Unlike profiles, data recorded in this geometry are hyperbolic even when the reflector is only locally horizontal at the reflection point. The common midpoint gather is the basic data used by most of the prevalent velocity estimators [Schneider and Backus (1968), Tanner and Koehler (1969), Sherwood and Poe (1972)].

Velocity estimation from CMP gathers amounts to determining which values of $t(0)$ and v best fit the arrivals displayed on the gather. Typically the determination of the best fitting parameters is made by actually trying many possible values of v for each $t(0)$ and then picking the velocity which fits best. The main differences between velocity estimators lie in the method of determining how well each trial velocity fits the data. Some methods use unnormalized cross correlation, others use semblance and still others use summing techniques. Figure 3 shows how velocity might be estimated using a summation measure. The estimated velocity depends to some extent on the coherence measure used, however for our purposes we can consider estimates to be independent of the coherence measure.

Up to this point we have discussed velocity estimation in terms of reflections from a single layer. Dix (1955) showed that for small

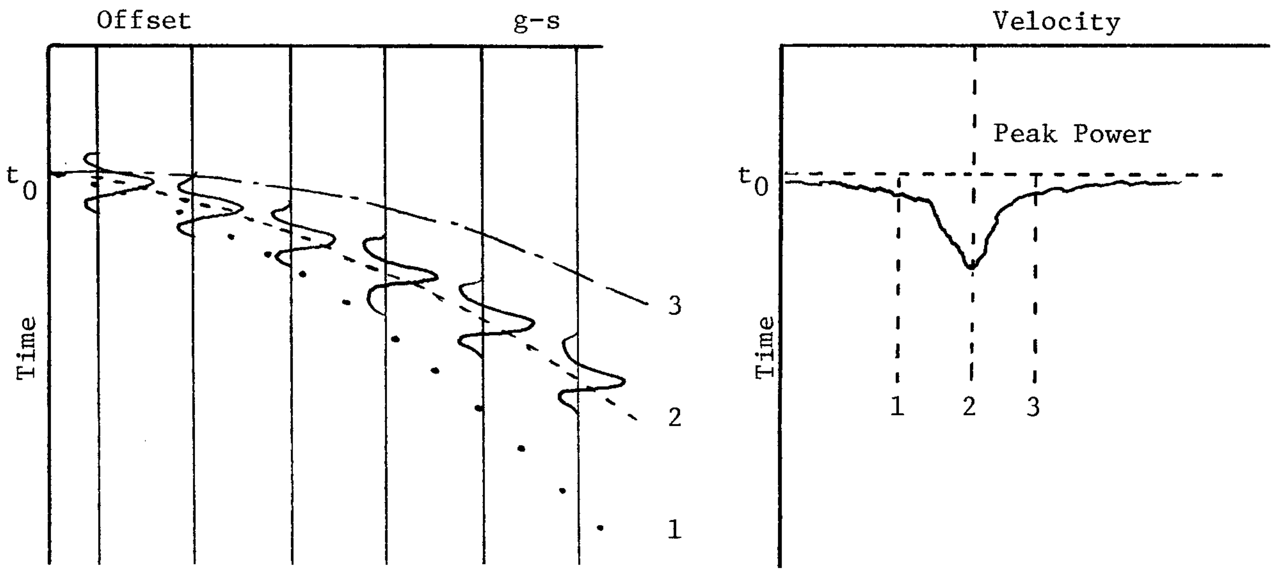

Figure 2-3. An example of velocity estimation. On the left is a CMP gather. The arrivals shown represent a plane layer reflection event. The dotted and dashed hyperbolas represent three sets of arrival times corresponding to three different velocities but having the same zero offset travel time. For the data shown here, velocity estimation amounts to determining which hyperbola best fits the event on the gather. Here, the power in a sum of the data along each hyperbola is used as a measure of goodness of fit. The graph on the right shows the power resulting from a sum of the data along each of the trajectories shown (others too). Since peak power occurs for lag pattern 2, the corresponding velocity, v_2 , would be the velocity estimate of this procedure. In this example we have summed only the data corresponding to zero offset travel time t_0 . In practice, the power in the hyperbola sums for all data having zero offset travel times within a gate around t_0 would be averaged in getting a velocity estimate for time t_0 . Averaging is used to suppress noise and to overcome the effects of finite length source wavelets.

shot-receiver offset, the reflections recorded over multi-layered velocity structures have arrival times which approximately satisfy equation (2-1). He also showed that for those reflections the best fit velocity in equation (2-1) was a type of average of the velocities of the layers above the interface causing the reflection. Specifically, the best fit velocity for the reflection from the bottom of the N^{th} layer is given by

$$v = \left[\frac{\sum_{i=1}^{N} v_i^2 \Delta t_i}{\sum_{i=1}^{N} \Delta t_i} \right]^{1/2} \qquad (2\text{-}2)$$

where v_i is the velocity and Δt_i is the two way vertical travel time in the i^{th} layer above the reflector.

For obvious reasons the velocity defined by (2-2) is called the rms velocity of the reflection. Shah and Levin (1973) demonstrate that for reasonable recording geometries and velocity structures, velocity error associated with fitting equation (2-1) to reflections from multi-layered media is usually less than 2%.

From the above discussion it should be clear that the basic assumption of the standard velocity estimation procedures is that the arrival times of reflections are hyperbolic when displayed on a CMP gather. We have already seen that this is not exactly true for multi-layered structures. In general, it is also not true when either velocity or reflector geometry is laterally variable.

Recording Geometries and Data Displays

As a final topic in this chapter we will discuss recording geometries and data displays. Typically, good quality marine reflection seismic data is recorded with an array consisting of one source and up to 48 or 96 receivers.

This array is towed by the recording vessel along some straight line which we shall call the 'k' axis. The source is activated periodically and the generated reflections are recorded. Data recorded for each source activation are by our previous definition a profile. Thus, as the boat moves along the 'k' axis, a series of profiles each with a different source position and reflection positions, are recorded. The source is activated often enough so that adjacent profiles share many of the same reflection points. Figure 2-4 indicates this type of recording geometry and shows some of the ways these data are normally displayed. The figure shows the spatial coordinates of the source and receivers for the data displayed in profiles, common offset sections and common midpoint gathers. A three dimensional display which contains all the seismograms recorded while the vessel moved along a particular portion of the 'k' axis is shown in Figure 2-5. We shall term this type of display a multi-offset section. Since velocity estimates are usually based on data generated by many sources, our ultimate goal in later chapters will be to develop techniques which are applicable to common offset sections, multi-offset sections and CMP gathers.

Figure 2-4 cont'd.

geophone coordinate). Note that all axes (g,s,x,y,h) are parallel to the boat path (k axis). As the boat translates along the k axis data are collected in the speckled region of the s-g plane. At each source activation reflections are recorded at receivers positioned along the receiver cable. We have darkened the position of the cable for several shot locations. Data recorded and displayed along these lines are called profiles. Data recorded and displayed along lines parallel to the sequence of positions occupied by a given receiver (along lines parallel to the y axis) are called common offset sections. Because each profile shares some common receiver positions data can also be displayed along lines perpendicular to the y axis. Such displays along the offset (h) axis are called common midpoint gathers. There is a fundamental difference between the amount of data that can exist along the midpoint (y) axis and the amount that can exist along the (h) or (x) axis. The maximum (h) or (x) extent of the data is determined completely by the receiver cable length. The maximum length of data in the (y) direction is unrelated to receiver cable length.

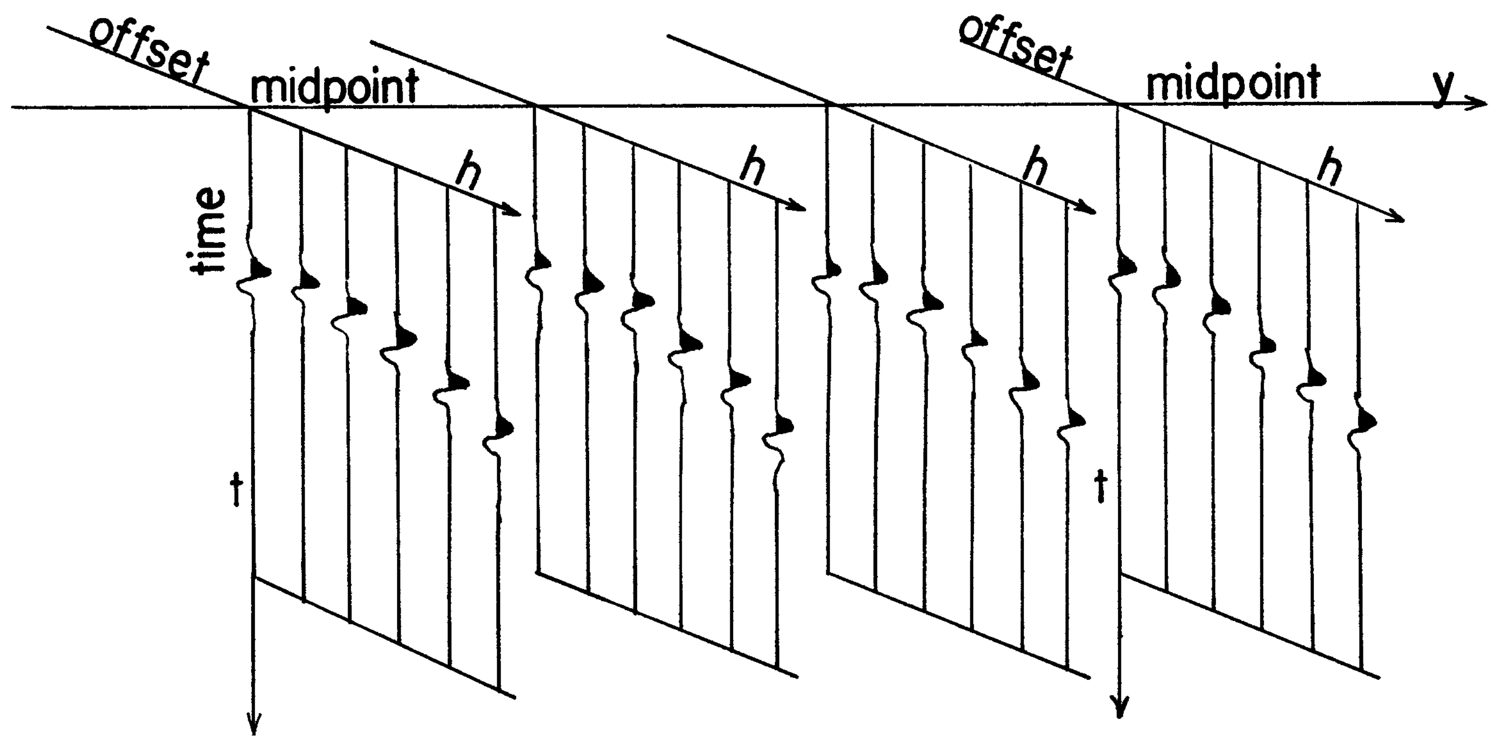

Figure 2-5. Data of a multi-offset section. A multi-offset section contains all the seismograms recorded along a particular traverse line. The seismograms of a multi-offset section are parameterized in terms of offset, midpoint and time. Thus, a multi-offset section may be thought of as either a section of common midpoint gathers or as a suite of common offset sections.