Finding Seismic Static Corrections

By DON W. STEEPLES
and GREGORYS. BAKER

Static corrections are made to seismic-reflection data to compensate for time shifts in the data caused by changes in topography and variations in near-surface seismic-wave velocity. Recent developments in ultra-shallow seismic imaging indicate that static time shifts in seismic data caused by relatively small changes in the thickness of very-low-velocity surficial layers may be significant.

The velocity-variation component of the correction involves what is commonly called the "weathered zone."

In some places the weathered zone consists mostly of unconsolidated, near-surface materials. It is not commonly realized that P-wave velocities in these shallow, unconsolidated materials can be substantially lower than the velocity of sound in air.

The primary purpose of this month's column is to show that when low-velocity surface layers are present, a thickness of even a few feet can have profound static effects.

Introduction

Most methods used to attack the static-correction problem depend upon using the near-surface velocity information obtainable from conventional seismic data. Methods include refraction statics, surface-consistent statics, cross-correlation statics and diving-wave tomography.

In most commonly encountered geologic situations one or more of the above-cited techniques may be sufficient. When using source- and/or receiver arrays in which the highest possible resolution is necessary, and under conditions where the near-surface geological conditions change quickly and in unpredictable ways, such approaches can be inadequate.

The problem in its most elementary form, with a point source and a two-geophone receiver array, is depicted in Figure 1.

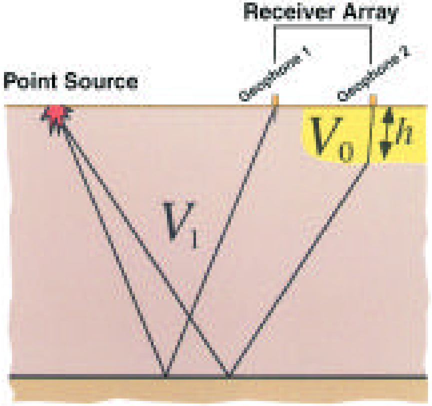

Figure 1. Simple point-source/receiver-array model with flat topography. The static shift from Geophone 1 to Geophone 2 is

$$\Delta tstatic = \frac{h[V_1 - V_0]}{V_0 V_1}$$

where Δtstatic is a first-order approximation assuming the angle from vertical of h is small (ratio of V_1/V_0 is large).

Note that in this case the surface topography is flat, but there is a variation in the thickness of the low-velocity material (V_0) that overlies a higher-velocity layer (V_1). When the velocity of the near-surface material is substantially less than the velocity of a P-wave in air, only one or two feet of variation in thickness in the near-surface layers can cause significant static shifts.

These problems can occur almost anywhere, but they are most common where a variable thickness of alluvial, fluvial, aeolian or glacial material overlies bedrock.

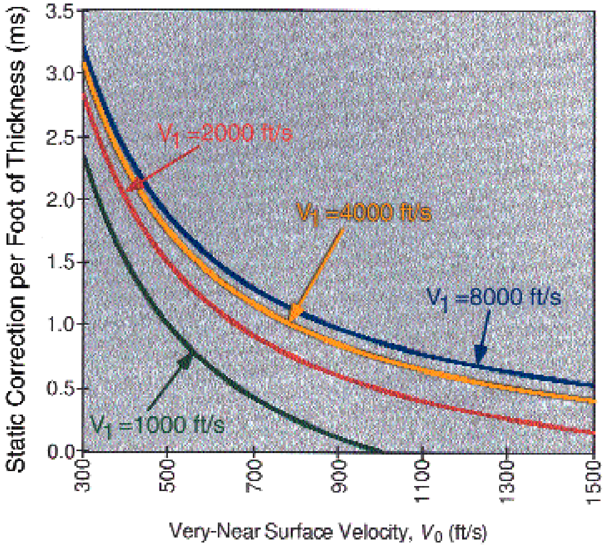

Figure 2. Static correction in ms/ft for various surface alluvial velocities (V_0) and various underlying-layer velocities (V_1). The situation modeled, and equation used, is shown in Figure 1. The static shifts for all V_1 velocities above 8,000 ft/s are only slightly larger than for V_1 = 8,000 ft/s.

The first-order static correction for the geologic situation depicted in Figure 1 is shown graphically in Figure 2: The amount of static correction necessary is highly dependent on the velocity of the

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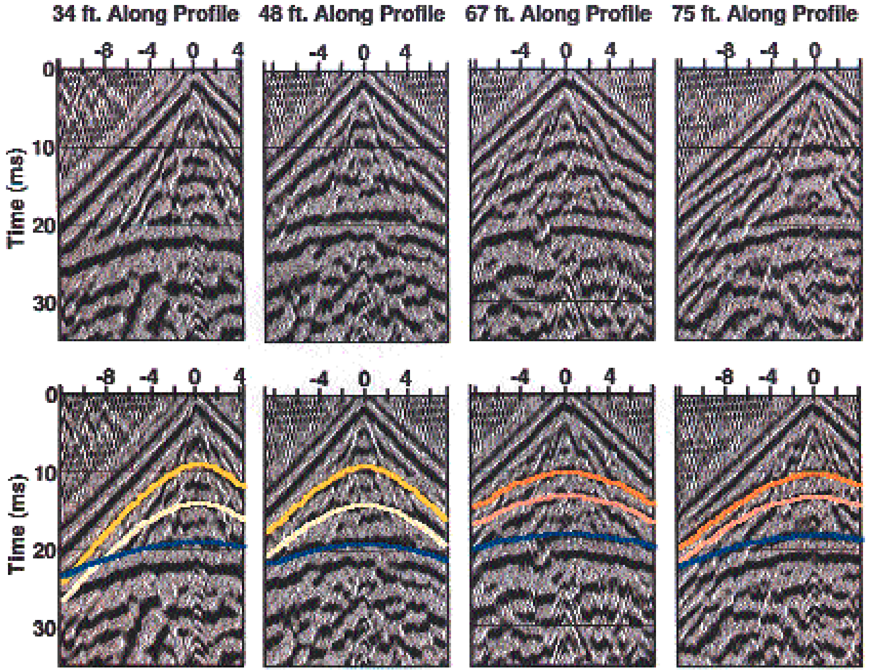

Figure 3. Four uninterpreted (top) and interpreted (bottom) representative field files from a recent ultra-shallow seismic-reflection survey near Great Bend, Kan. The horizontal axis is source-to-receiver offset in feet. The source was a single shot from a .22-caliber rifle, and the single-geophone group interval is two inches. Digital frequency and f-k filtering has been applied, as well as AGC scaling. The lateral distance from the shotpoint on the left to the shotpoint on the right is 40 feet. Within that distance, the weathering velocity changes from 518 ft/s to 682 ft/s, without noticeable surface topographic or soil variation. The event in blue is the water table, at a depth of eight feet.

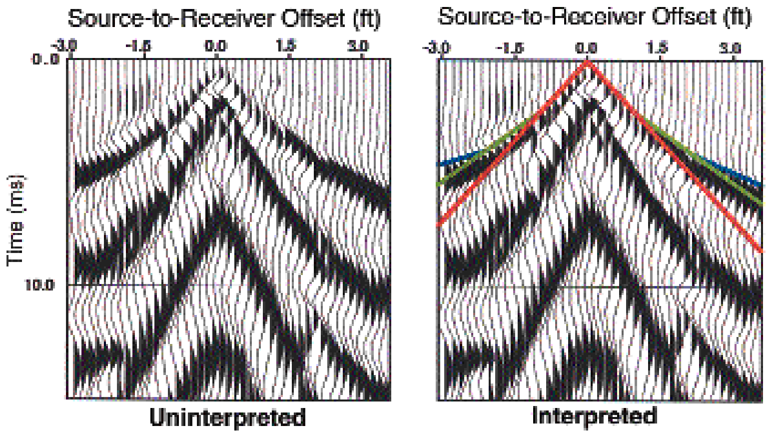

Figure 4. Uninterpreted and interpreted field file generated by stacking five spark-plug-generated events. Note the time scale and that the near-source first-arrivals have a dominant frequency greater than 1 kHz.

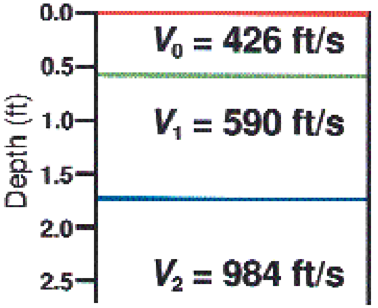

Figure 5. A1-D solution to the three-layer problem from the first arrivals picked in Figure 4.

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unconsolidated material (V_0) and is not strongly dependent on the velocity of the underlying higher-velocity layer (V_1).

Under conditions similar to those presented in Figure 1, knowing both the velocity and the thickness of the V_0 material is especially important.

Very-near-surface P-wave velocities are commonly 800 to 1,500 ft/s. In Figure 2, the static correction for these materials ranges from about 0.8 ms to 0.2 ms per foot of thickness, respectively.

The real problem arises when velocities of less than 600 ft/s are encountered in near-surface materials, as these low velocities produce static corrections of more than 1 ms per foot of thickness. An error of only one foot in calculating the thickness of near-surface materials with a velocity of 500 ft/s, for example, results in a static-correction error of 1.5 ms.

Many seismologists believe that P-wave velocity in earth materials is never less than about 1,100 ft/s (the velocity of sound in air). The Wyllie-equation argument says that the seismic P-wave velocity in a material is an average of the velocity in the pore fluid (air) and the mineral grains through which the seismic wave passes.

This argument is used in the analysis of borehole sonic logs in water-saturated solid rock, where it usually works quite well.

In reality, the Wyllie-equation argument has very little to do with the P-wave velocity in unconsolidated materials, because velocity is dependent only upon the shear modulus, the bulk modulus and the density of the total material, not on the average of these properties for the constituent materials.

The other reason that 1,100 ft/s is often quoted as a minimum velocity is

See **Geophysical Corner***, page 29*

Geophysical Corner

from page 21

that most seismic sources emit some audible sound, called air wave, into the air. When the velocity in the near-surface material is less than 1,100 ft/s, the first arrival at geophones within a few feet of the shot is the air wave.

In such cases, investigators sometimes erroneously pick the air wave as the first seismic P-wave arrival.

Ultra-shallow velocity measurements

Figure 3 shows four representative field files from an ultra-shallow seismic-reflection survey conducted near the Arkansas River a few miles east of Great Bend, Kan. The first reflections come from the boundaries between intra-alluvial layers at depths of two to four feet. The deepest reflection is from the water table, at a depth of about eight feet.

The interval velocity varies quickly from less than 650 ft/s above the water table to more than 2,000 ft/s below it.

To obtain this degree of detail, geophone intervals of two inches were used. The seismic source was a single, .22-caliber rifle shot, using short ammunition, with the tip of the rifle barrel inserted about four inches into a 3/4-inch-diameter hole in the ground. The dominant frequency is about 450 Hz, which, when combined with the near-surface velocity of 623 ft/s, provides a 1/4-wave length vertical resolution limit of approximately five inches.

To determine the velocities even closer to the surface, we have obtained P-wave velocity measurements with refraction surveys using an automotive spark plug as an energy source. We obtained a 100-foot-long spark-plug wire from an automotive supply company and hooked one end of the wire to the distributor of a vehicle and the other end to a spark plug placed in a hole 1/2-inch deep and 1/2-inch in diameter, located about one inch from the nearest geophone.

Although it has very low power, the spark plug is a highly-repeatable high-frequency source.

Figure 4 shows a detailed ultra-shallow field file from a test site in Lawrence, Kan., using the spark-plug source. The velocity of the near-surface material varies from about 450 ft/s to about 1,000 ft/s (Figure 5).

Discussion

In the first section, we showed the potential effects of very-low near-surface velocities on intra-array static shifts. In the second section, we presented examples of seismic data in which P-wave velocities as low as 450 ft/s were observed using both reflection and refraction methods.

Making static corrections becomes more difficult as high-resolution seismic-reflection data are pushed to progressively higher frequencies. For example, a static-correction error of three ms would cause 160-Hz dominant-frequency seismic-reflection data to stack 180 degrees out-of-phase. The static correction necessary for varying thickness of low-velocity unconsolidated materials is sometimes in excess of one ms per foot of thickness of the material.

We believe that having accurate information about the velocity and thickness of near-surface materials is essential to removing static shifts in conventional reflection surveys when source- and/or receiver arrays are used in a geologic region with very-low-velocity, near-surface materials. ❏