[GC] Acquiring Shear-Wave Data in Seismic Programs*

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General Statement

For decades, seismic analysis of subsurface geology has been limited to information that can be extracted from compressional-wave (P-wave) seismic data – but numerous geophysicists are now becoming aware of the advantages of combining shear-wave (S-wave) data with P-wave data. The advantage, simply stated, is this: A broader range of rock and fluid properties can be estimated than what can be estimated with P-wave data alone. The purpose of this article is to explain that it may be easier and less costly than you think to acquire S-wave data across onshore prospect areas when conventional P-wave seismic data are being collected.

P and SV Wavefields

Seismic sources used to acquire P-wave data across land-based prospects always apply a vertical force vector to the Earth. This statement is true for vibrators (the most common land-based P-wave source), explosives in shot holes and the various types of weight droppers and thumpers that have been utilized to acquire P-wave data over the years.

When a vertical impulse is applied to the Earth, two types of wavefields radiate away from the impact point – a P wavefield, and an SV (vertical shear) wavefield. (A minor amount of SH – horizontal shear – energy also radiates away from the application point of a vertical impact, but this S-wave mode is weak and will not be considered in this discussion.) Two examples of the relative energy that is distributed between a downgoing P wavefield and a downgoing SV wavefield produced as the result of a vertical impulse are illustrated on Figure 1. These P and SV radiation patterns correspond to different values of Poisson's ratio for the Earth medium where the vertical impulse is applied.

A surprising principle to many people, including geophysicists, is that although a vertical-impact source is considered to be a P-wave source, the SV wavefield produced by such a source is often more robust than is its companion P wavefield.

For example, to determine the relative strengths of the downgoing P and SV wavefields at any take-off angle from the source station, one has to only draw a raypath, such as dash-line SAB on Figure 1, oriented at take-off angle Φ. The points where this line intersects the P and SV radiation pattern boundaries define the relative strengths of the P and SV modes in that illumination direction. For take-off angle Φ in this example, the strength (B) of the SV mode is larger than the strength (A) of the P mode.

Example

A real-data example that illustrates this physics is displayed as Figure 2. This example is a vertical seismic profile (VSP), which is one of the best measurements that can be made to understand seismic wave-propagation physics.

Here, both a downgoing P wave and a downgoing SV wave are produced by the vertical vibrator that was used as the energy source. Either wave mode, P or SV, can be used to image geology. Both modes are embedded in the data, but people tend to utilize only the P-wave mode.

Conclusions

How can we begin to take advantage of the SV-wave data that conventional land-based P-wave seismic sources produce? Only two alterations have to be made in conventional seismic field practice:

● Deploy three-component geophones rather than single-component geophones.

● Lengthen the data traces to ensure that SV reflections produced by the downgoing SV wavefield are recorded. Because SV velocity is less than P-wave velocity by a factor of two or more, SV data traces need to be at least twice as long as the traces used to define P-wave data.

These alterations can be done with minimal cost, and the potential benefits of acquiring two S-waves (P-SV or converted shear, and SV-SV or direct shear) rather than just P-wave data can be immense. Our profession needs to utilize longer data traces when acquiring all landbased seismic data.

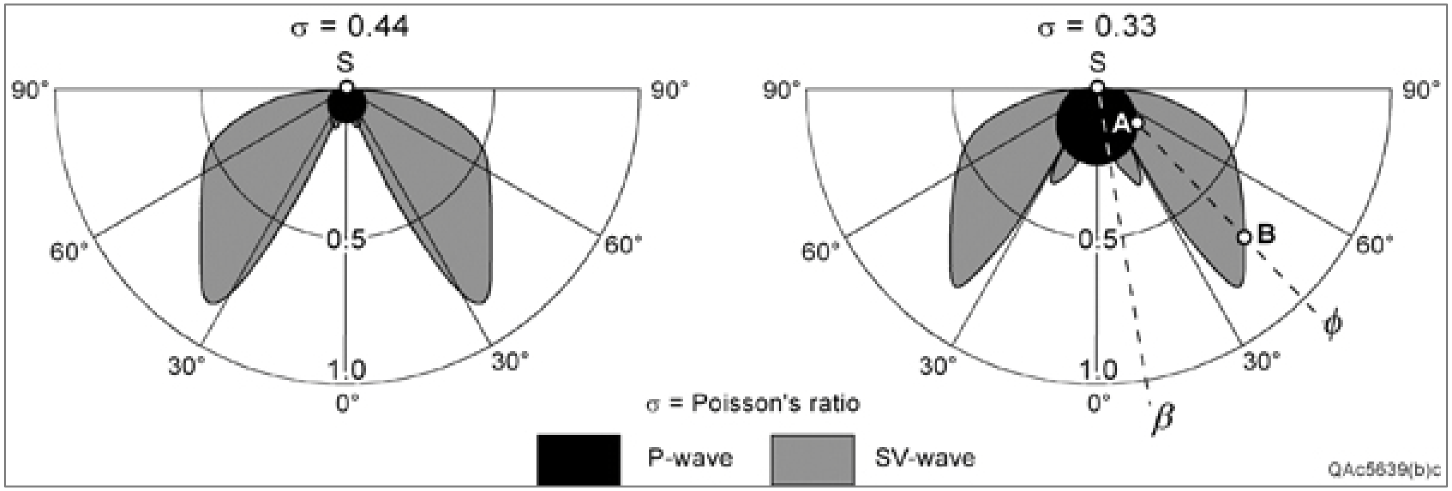

Figure 1. P-wave and SV-wave radiation patterns produced when a vertical impulse is applied to the Earth surface at source station S. These patterns define the relative strengths of the illuminating wavefields, not the geometrical shapes of the wavefields. For example, at take-off angle Φ, the strength of the downgoing P wavefield is A, and the strength of the SV wavefield is B. The quantity σ represents the Poisson's ratio of the Earth half space.

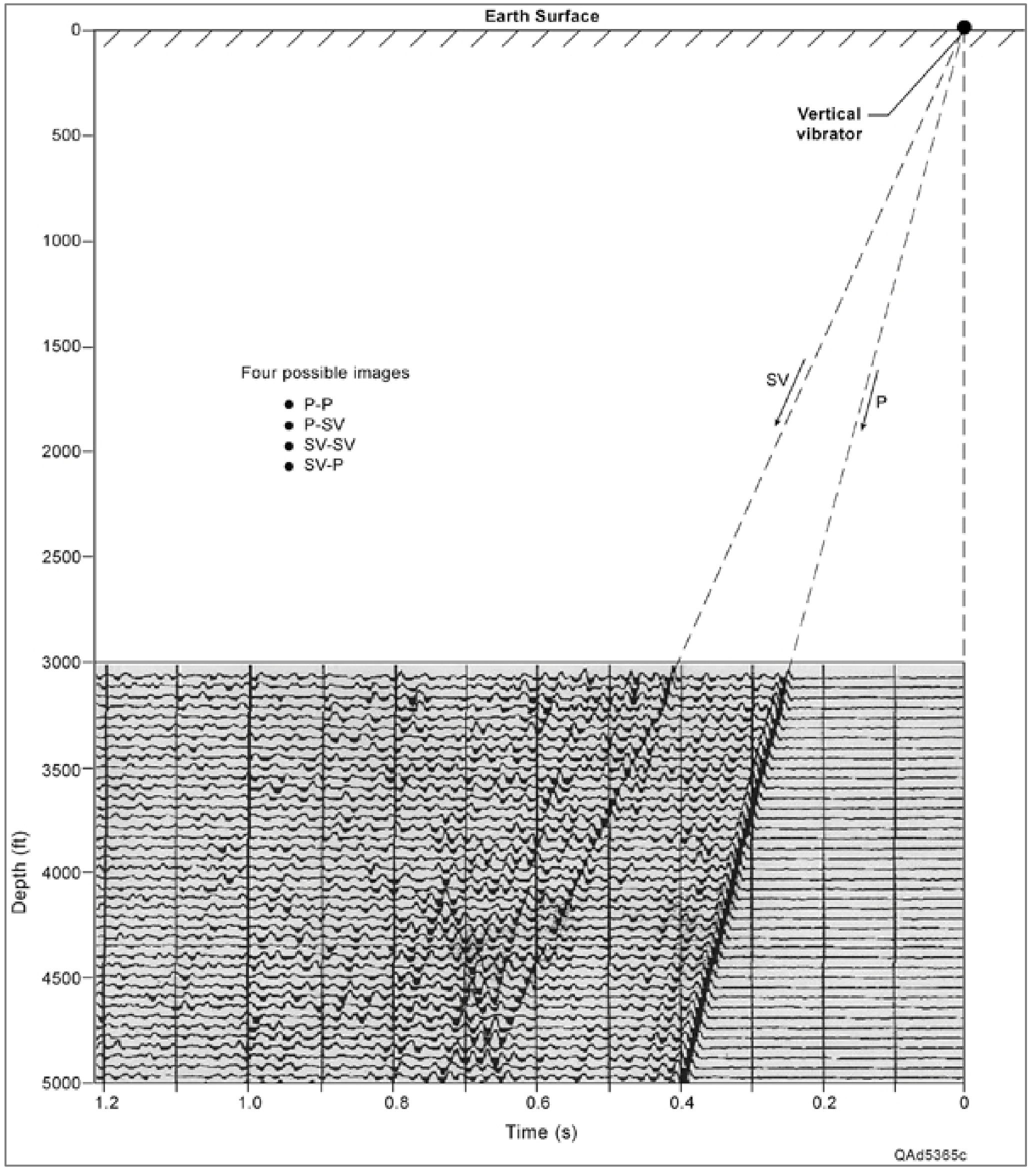

Figure 2. VSP data showing downgoing P and SV modes produced by a vertical vibrator. In this example, the vibrator was close to the vertical well in which the downhole geophones were deployed, which would be a near-vertical take-off angle such as β in Figure 1. Across the depth interval 3,000 to 5,000 feet, the velocity of the downgoing P wave is approximately 13,300 ft/s, and the velocity of the downgoing SV mode is approximately 8,000 ft/s. If long data traces are recorded, there is the potential to construct four images (P-P, P-SV, SV-SV, SV-P), where the first term defines the downgoing wavefield and the second term identifies the upgoing wavefield.