DELINEATION OF
SHALLOW GULF COAST STRUCTURE
AND STRATIGRAPHY USING
SEISMIC SHEAR WAVE REFLECTIONS

By T. L. Dobecki and J. Steele

INTRODUCTION
The geologic depositional environment composing most of the Texas Gulf Coast Region has, generally, defied attempts by geophysical technology to consistently provide interpretation of shallow stratigraphic changes. The use of shear waves in seismic refraction studies was described in an earlier paper (Dobecki, 1989). This study showed how shear waves could be used to discriminate between changes in saturation and changes in lithology. One of the key findings is that in soils, such as are typical for Holocene and Pleistocene sediments in the Gulf Coast region, the ratio of compressional wave velocity to shear wave velocity may be anywhere from as low as 3:1 or, as we have discovered during recent tests, to as high as 10:1. In saturated sediments in the Gulf Coast area, P-waves travel typically from 5-10 times faster than an S-wave in the same setting. The ability to interpret a small layer or object using seismic reflection is directly a function of the seismic wavelength (shorter wavelengths can resolve smaller targets). Wavelength, $\lambda$, is defined for a single frequency wave as:

$$\lambda = \frac{V}{f}$$

where $V$ is the frequency of the wave and $\lambda$ is its propagation velocity. Using very slow waves (like shear waves), this will allow much smaller features to be seen than by using the faster, but more commonly used, P-wave methods. For example, if we can induce a 100 Hz wave into the ground ($P$-or $S$-wave) then the corresponding wavelengths (in a saturated soil) would be 50 ft. for the 5,000 ft./s P-wave and only about 6 ft. for the 600 ft./s S-wave. As geophysicists feel they can resolve target sizes of the order of $\lambda/4\lambda$, this means we can detect thickness or depth changes of about $\lambda/10\lambda$, or 5-10 fold in the $P$-wave while the S-wave should be able to detect changes of as small as $\lambda/3\lambda$. From this theoretical standpoint, then, we can automatically gain a 5- to 10-fold increase in our "high resolution" capability for seismic reflection merely by switching from $P$-wave reflection to $S$-wave reflection. The benefits to be gained include:

- The ability to detect shallower events (we have detected fill/sand interfaces at 15 ft.)
- The ability to see both top and bottom of fairly thin beds (on the order of 5 ft. thick).
- The ability to profile data along lines with very good lateral resolution.

Historically, the type of geophysical surveys used to map, for example, buried abandoned channel systems of the Holocene and Pleistocene formations have included seismic refraction, ground penetration radar, or electrical resistivity-based methods.

Reflection requires substantial contrasts in velocity between the clay and sand deposits; thus, this method is often unsuccessful. Electrical resistivity methods do not have the capability of defining small changes, and typical Gulf Coast sediments are all so conductive that it is difficult to detect any contrast of significance between target horizons. Ground penetrating radar does not have the capacity to penetrate but a few feet into these highly conductive surface soils typical of the Gulf Coast area. So, we are largely left with closely spaced drilling to resolve such questions as identification of depositional boundaries, location of growth faults, and thickness and continuity of aquifers/aquicludes. In recent months, we have tested and applied shear wave reflection techniques to such problems and have found that they do, indeed, follow theory and have proven to be a very useful and cost effective adjunct to a drilling program.

FIELD METHODOLOGY
A seismic reflection investigation using $S$ waves is conducted similarly to the way $P$ wave reflection surveys are conducted.

1. An energy source is introduced at the ground surface.
2. Geophones are used to sense refracted and reflected returns from the subsurface.
3. A seismograph is used to record the data.

![Illustration of field method for imparting shear waves into the ground using a hammer, steel plate, and a sideways hammer swing.](image)

The only difference between the field methods is that with an S-wave survey, we use a source which generates strong shear waves and use geophones which also respond more strongly to shear waves. As described in the earlier paper (Dobecki, 1989) and, as shown on Figure 1, we use the horizontal impact of a sledgehammer to generate the S-waves, and we use horizontal-axis geophones to record the waves. The data acquired, then, are rich in shear waves. Beyond this, recording and processing follow the same procedures as for the more common P-wave surveys. As an example, Figure 2 shows a raw shot record for a series of three hammer blows (horizontal) as recorded by a series of 24 horizontal geophones. The spacing is 10 ft. from the closest geophone and the geophones have a two-foot spacing. Several reflections are evident even on this raw, unprocessed recording. While the reflections come in at fairly "late" reflection times (0.200 - 0.400 seconds), they represent reflections in the 50-100 ft. (15-30 m.) depth range because of the slow velocity of the shear waves — estimated at 400 ft./s in this example.

CASE HISTORIES

Two case histories using the shear wave reflection techniques are described in the following sections. The case histories include a geologic fault investigation in Harris County, Texas and a stratigraphic study in Jefferson County, Texas.

Example 1 — Fault Study, Houston Area

Standard practice in site evaluation in a region subject to growth faults includes a determination of the location and severity of faulting that might exist at a site (Van Siclen, 1985). Our case history describes a site that is adjacent to a known, mapped fault. Projection of the trend of the known fault suggests that it may cross into the subject property. Our total field investigation program consisted of: a) shear reflection surveying of two lines across the projected fault trace; b) drilling of five boreholes across the projected trace of the fault, and c) geophysical logging of each borehole to identify common stratigraphic markers and to ensure proper hole-to-hole correlation.

Figure 3 presents a segment of one of the seismic reflection sections. These data, as shown, were produced in the field with minimal post-acquisition processing (frequency filtering). The flat, continuous nature of the reflection events is interpreted as representing an unfaul ted subsurface section. The deepest reflection seen is the order of 250 ft. (76 m.) below. For the purpose of fault mapping, no effort has been made to correlate specific reflections with specific stratigraphic horizons. We are simply trying to determine if offsets indicative of fault displacement are present, and they are not.

The project site is situated on the surface outcrop of the Lisse Formation. Past experience with the Lisse Formation had revealed reliable marker beds at sand/clay interfaces. The interfaces are interpreted to represent contacts between stacked channel systems and flood basin and/or channel fill depositional environments. Based on our experience in the study area we picked a test hole depth of 300 ft. (91 m.) in order to penetrate the Lisse, hopefully.

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**Figure 2.** Sample, raw seismic recording of shear wave reflection data. The events noted by arrows are a series of reflections. Trace spacing is two feet.

**Figure 3.** Single fold, unprocessed reflection section at fault study site. Key feature is non-displaced, horizontal reflectors.
completing the test holes in the Willis formation. The cross-section of the borehole logs, Figure 4, correlates with the reflection interpretation, in that level, continuous bedding is present.

Our net interpretation from seismic sections and borehole-to-borehole correlation is that the mapped fault either dies out before crossing into this property, or turns away from the property.

**Example 2 – Stratigraphic Study, Jefferson County, Texas**

As part of a construction planning program, our client required mapping of the depth and thickness of a specific (Beaumont clay) horizon with a ±3 ft. accuracy. The shallow depth (30-50 ft.) of the top of this clay, its small thickness (approximately 20 ft.), and the generally groundwater-saturated conditions eliminated P-wave reflection from consideration and made shear wave reflection a prime consideration. Owing to the very close tolerances required by our client, these shear reflection data were acquired in a slower, more painstaking procedure than the first example; also we subjected the resulting data to a more expensive post-acquisition processing procedure. An example of a resulting seismic reflection section is given by Figure 5. The target clay is only on the order of 20 ft. thick. As shown on Figure 5, both the top and bottom reflections of the clay layer were identified. We also are able to map an even shallower (approximately 15 ft. deep) horizon which is the top of a sand unit as well as several deeper interfaces below the clay. The seismic interpretations correlated very well with the stratigraphy at the site as verified by borehole drilling and sampling along the seismic lines. From the seismic section, we are able to observe minor structure on the units as well as an interpreted thinning of the target clay layer in the central portion of the section.

**CONCLUSIONS**

The seismic shear wave reflection technique used to identify distinct stratigraphic layers and stratigraphic marker off-sets indicative of subsurface faults has been demonstrated to be a useful field investigative tool. The principal advantage over competing geophysical techniques (e.g., P-wave reflection/refraction or electrical methods) is the combination of reasonable depth of penetration plus very fine detail which can be obtained because of the very short seismic shear wavelengths in these Gulf Coast sediments. Using this method along with limited borehole geophysical log data is a cost-effective method for field investigative techniques.

**References Cited**


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Figure 4. Correlated geophysical logs from borings along seismic line at fault site.

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**T. L. DOBECKI—Biographical Sketch**

Dr. Thomas L. Dobecki is an Associate with the geoscience consulting firm of McBride-Ratcliff and Associates, Inc. of Houston, Texas. He received a B.S. (physics), M.A. (geology) and Ph.D. (geophysics) all from Indiana University. Since completion of his schooling, he has worked primarily as a geotechnical and groundwater geophysicist, having been chief geophysicist for D'Appolonia Consultants, staff research geophysicist at Sandia National Labs, and an associate professor of geophysics at the Colorado School of Mines. Professionally, he has served as

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J. STEELE—Biographical Sketch

Jack Steele is a Project Manager in the geoscience and regulatory service groups of McBride-Ratcliff and Associates, Inc. He received a B.S. (geology) from Lamar University, Beaumont, Texas in 1978. Since graduation, he has worked as a geotechnical and environmental consultant. Since 1980, he has performed numerous surface and subsurface geologic fault evaluations throughout the Gulf Coast area of Texas. He currently serves as Treasurer for the Texas Section of the Association of Engineering Geologists and has been a member of the Houston Geological Society since 1982.

Figure 5. Twelve-fold, processed seismic section at clay mapping project site.