Why Apply the FMDSM Technique on Acquired DST Seismic Data?

BCE has published several papers on the application of techniques that utilize Fermat's principle, which states that the raypath travels along the trajectory which requires minimum time between points, and adhere to Snell's law for refraction at stratigraphic boundaries (see http://www.bcengineers.com/technicalnotespapers.html). In BCE's software the Forward Modeling / Downhill Simplex Method (or FMDSM) is made available as the analysis technique for this purpose, and in Technical Note 1 the features of this method are described in more detail (http://www.bcengineers.com/images/BCE_Technical_Note_1.pdf).

The recent CPT-14 conference in Las Vegas has enforced BCE's view that methods similar to the FMDSM must be applied to analyze Downhole Seismic Testing (DST) data. At this conference Professor Jonathan Bray (UC Berkeley) gave a very interesting keynote lecture on liquefaction in general and the extensive geotechnical analysis of the catastrophic liquefaction that occurred in Christchurch, New Zealand in 2010 and 2011 (http://www.cpt14.com/cpt14-papers). This analysis showed very clearly that near surface rather than deep liquefaction resulted in extensive foundation damage, and because of that is essential to obtain accurate near surface values for the shearwave velocity from DST.

For near surface investigations the seismic source must not only be decoupled from the testing rig, it must also have a relatively large radial offset (>2.5m) from the downhole seismic sensor. This offset allows the source wave to refract and travel within stratigraphic layers for an extended time, which dramatically increases the characterization of the layer or depth under analysis. It also should be noted that the displacement field generated by a single body force contains both near-field and far-field terms, with the near-field decay terms proportional to r^{-2}, while the desired far-field terms (P and S waves) decay as r^{-1} where r is the travel distance from source to receiver. Therefore larger radial offsets significantly decrease near field amplitudes (as the value for r is increased) resulting in significantly higher signal-to-noise ratios of the recorded seismic data. In addition, in SCPT this approach of decoupling and large radial offsets results in minimal recording of "rod" noise, which can be very important for SH source generation in soft surface material that require large hammer source impacts. Obviously when applying larger radial sensor-source offsets the implementation of Fermat's Principle must be taken into account when analyzing the obtained data.

BCE has found that decoupled and relative large sensor-source radial offsets can result in outstanding data sets. Figure 1 illustrates unfiltered real SCPT data (triaxial configuration) acquired with PCB accelerometers where a decoupled sensor-source radial offset of 3 meters was applied. Right and left polarized SH steel plate "point" sources with specially designed traction ribs were utilized to generate this data set. The steel plates were placed underneath the tires of a vehicle, whereby the air filled rubber tires allowed lateral displacement of the steel plates upon impact, while still maintaining a large vertical force to stop steel plate/ground slip (see http://www.bcengineers.com/images/BCE_Technical_Note_4.pdf).

This SCPT data set was acquired within cemented layers where a push refusal was reached just below 5m. As is shown in Figure 1, the recorded near surface source waves have very high S\N ratios.

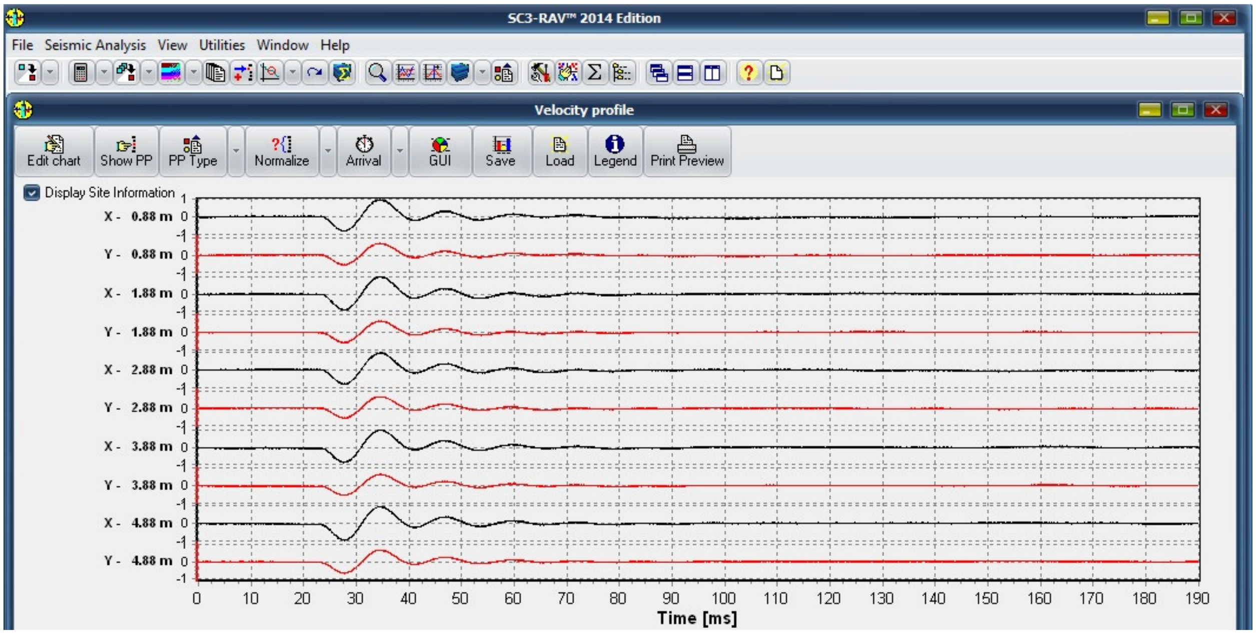

Figure 1. Triaxial SCPT data acquired at depths 0.88m, 1.88m, 3.88m, and 4.88m demonstrating very high S\N ratios.

Figure 1 illustrates very close source wave arrival times at each depth increment, and these arrival times are listed in Table 1. When processing this data set utilizing the straight ray assumption (SRA) it would appear that nonsensical SH wave source waves were recorded with interval velocities exceeding 5800 m/s, as is illustrated in Table 2. Table 2 also shows the interval velocities derived with FMDSM, resulting in very reasonable interval velocities. The FMDSM results are also shown in Figure 2, which clearly shows the ray tracing.

Table 1. Arrival times

Depth [m]	Arrival Time [ms]
0.88	22.3
1.88	22.46
2.88	22.565
3.88	22.79
4.88	23.42

Table 2. Estimated interval velocities

Depth [m]	Interval Velocity - SRA [ms]	Interval Velocity - FMDSM [ms]
0 - 0.88	N/A	140.2
0.88 - 1.88	2588	172.8
1.88 - 2.88	5891	249.8
2.88 - 3.88	3313	378.5
3.88 - 4.88	1346	514.8

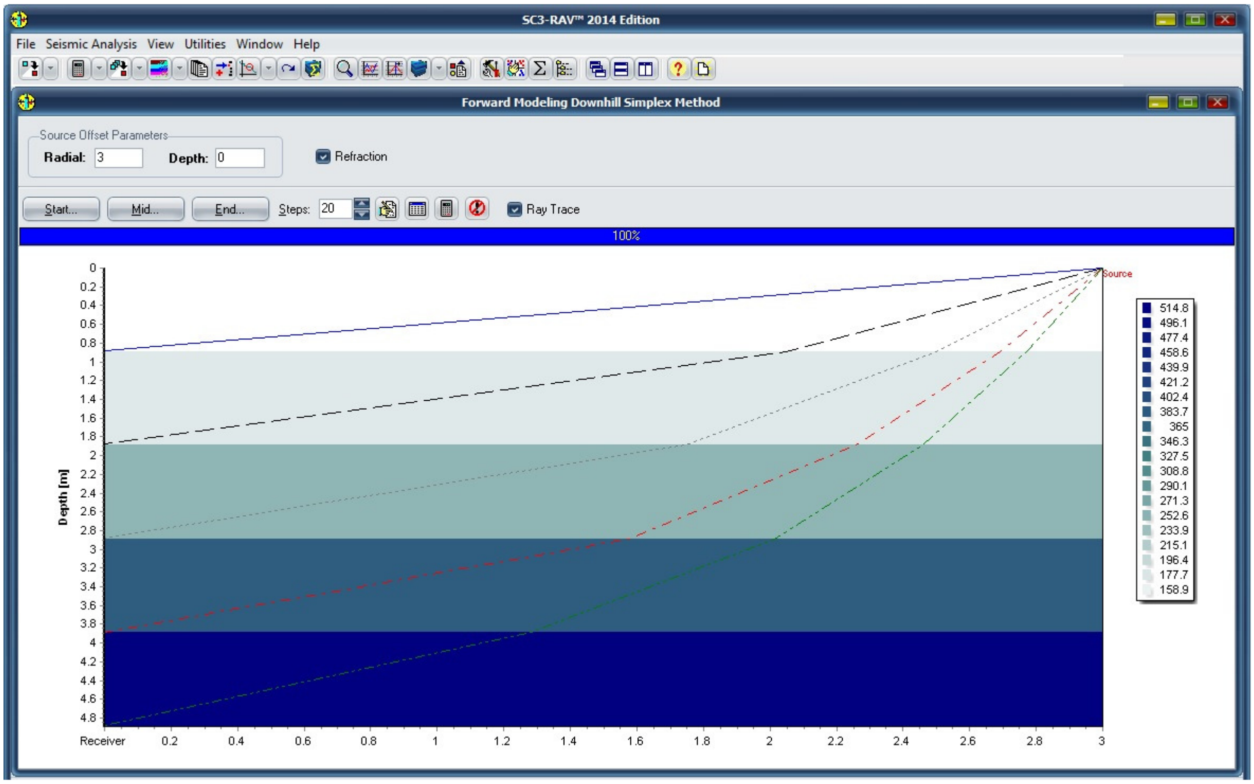

Figure 2. Graphical iterative forward modeling results (with ray tracing displayed) for FMDSM interval velocity estimates outlined in Table 2.

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