Application of Batch *Polarization Analysis* for SH wave Analysis in SCPT

The most widely conducted SCPT investigations are those that utilize a horizontally polarized shear wave (SH) source, generating particle motions that are orthogonal to the raypath and restricted to the horizontal plane as is illustrated in Figure 1. While a uniaxial sensor configuration can be used in such investigations, biaxial or triaxial seismic sensor configurations are preferred as they allow the full two dimensional particle motions to be recorded. However, when processing the SH data it can be challenging to obtain the source wave from both the X and Y axis recordings, especially since the rod string can rotate with depth, which causes the dominant amplitude responses on the X and Y axis to change.

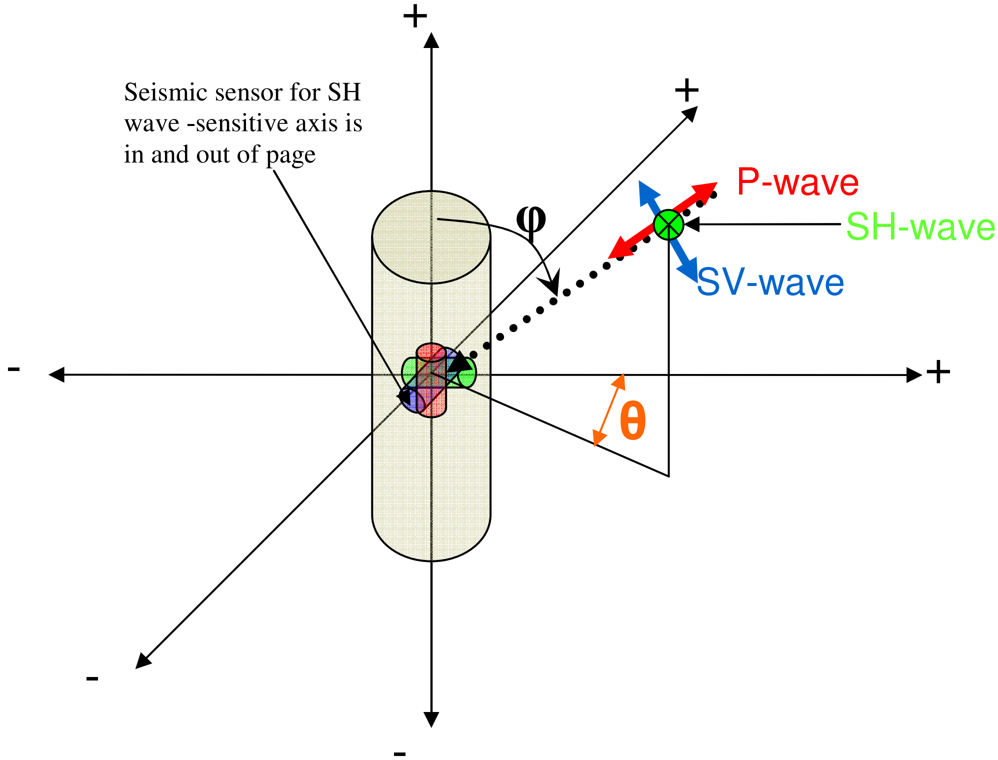

Figure 1. Source P, SV, and SH body waves impacting upon a triaxial sensor package.

Polarization with Hodogram Analysis (PHA) is a useful mathematical technique to process SH wave recorded seismic data. PHA facilitates F*ull Waveform Analysis* (FWA) where the recorded seismic source wave data from the X and Y axis are rotated onto a single full waveform wave axis, which also increases the signal-to-noise ratio.

The PHA and corresponding FWA procedure is summarized as follows:

- A time window is first applied to the seismic event of interest.
- The X, Y, and Z component seismic time series amplitudes are plotted against one another (ie., hodograms) within this time window.
- A least squares straight line best fit is applied to the hodogram. This straight line best fit provides angle of incidence information.
- Finally, a covariance matrix is calculated for the hodograms. The eigenvalues of this covariance matrix allow for linearity calculations. Highly accurate hodograms have a linearity approaching 1, while low accuracy hodograms have linearity near 0. Hodograms which have high linearity imply highly correlated responses.

These steps are illustrated in Figures 2 and 3. Figure 2 shows SH wave recordings on the X, Y and Z axis acquired with a triaxial sensor configuration. From the figure it is clear that there is minimal or no SH source wave recordings on the Z axis (as expected) and nearly equal source amplitude recordings on the X and Y axis (implying θ = 45º in Figure 1).

Figure 3 illustrates the calculated hodograms showing a very high linearity (0.999) between the X and Y axis responses. Figure 3 also shows the resulting full waveform (FW - (ρ(t))) where the investigator can process a single FW as opposed to the X and Y axis recordings.

Figure 2. X, Y and Z axis seismic recordings from a SH SCPT investigation. Specification of time window T1 and T2 so that hodograms can be calculated.

As evident from the previously outlined steps and Figures 2 and 3, the application of PHA requires significant user interaction (e.g., identification of the source wave and specification of the time window). In addition, the FW's maximum amplitude typically has to be adjusted by 180° depending upon the variability of the dominant X and Y axis amplitude responses (which can change with depth due to rod rotation and minor variations in equivalent amplitude responses).

The 2014 release of ***SC3-RAV***™ allows for batch PHA, which includes the identification of the dominant source wave, hodogram time window and phase correction. This has been accomplished by applying automated first break analysis and utilizing frequency spectrum analysis. In addition to batch PHA, batch signal decay has also been incorporated into the software, so the source wave pulse can be isolated.

Figure 4 illustrates SH SCPT X and Y axis data acquired at a mixed tailings dam in New Zealand. A digital bandpass filter of 30 Hz to 100 Hz was applied and option *Normalize Locally* was selected for the graph. With this option the amplitudes of the X, Y and Z axis each depth are normalized with respect to the absolute maximum value recorded for this set of triaxial data. Figure 4 clearly shows that there was rod rotation, causing the dominant X and Y axis amplitude responses to change with depth. Figure 5 illustrates the seismic data in Figure 4 after the application of batch PHA and signal decay, whereby the isolated FW with the correct phase is generated. This approach dramatically simplifies the process of obtaining reference arrival times for interval velocity calculations by processing only one waveform. This process also generates the FW, which allows absorption estimates.

Figures 6 illustrates a SH SCPT profile from the same test site where θ ≈ 45º in Figure 1 (i.e., nearly equivalent amplitude responses on the X and Y axis). Figure 7 illustrates the seismic data in Figure 6 after the application of batch PHA and signal decay. As is shown in Figure 7, the FW has been has been isolated with correct phase.

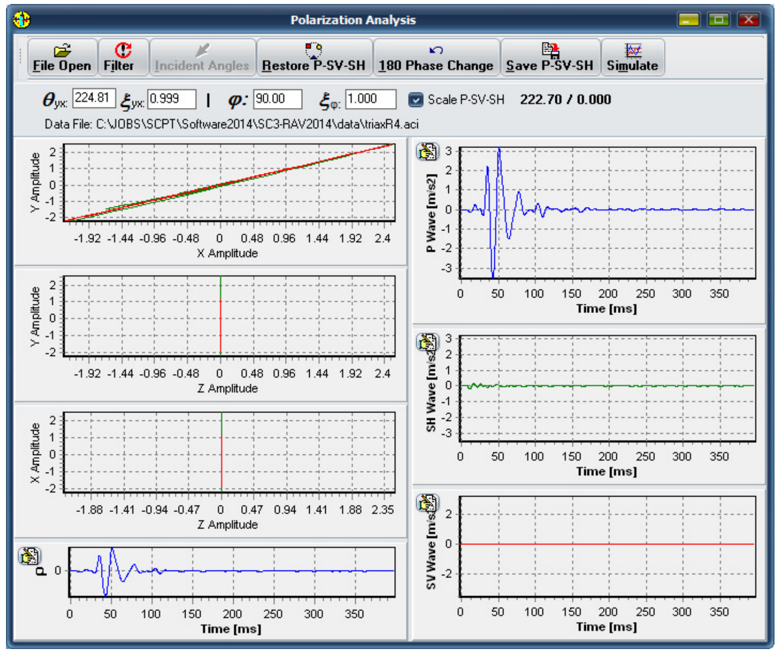

Figure 3. Application of hodograms and polarization analysis to seismic traces illustrated in Figure 2. Resulting FW is also displayed (ρ(t)).

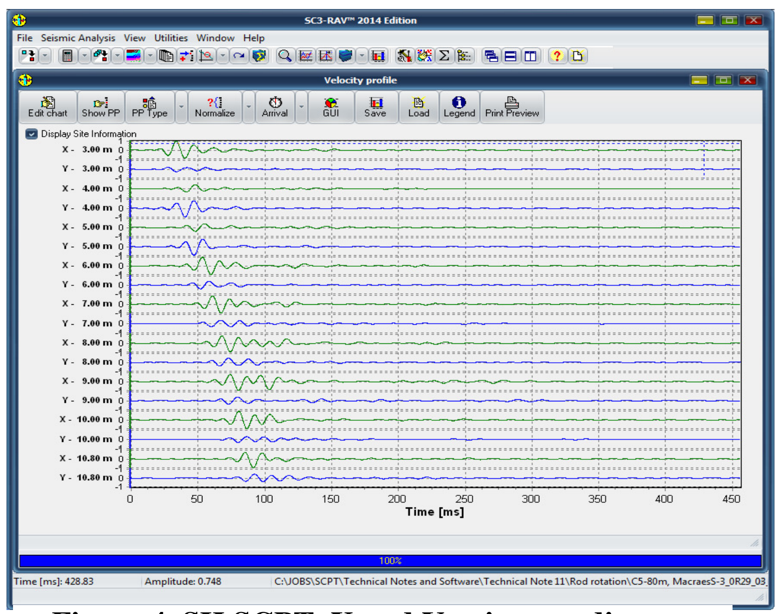

Figure 4. SH SCPT X and Y axis recordings where a 30 Hz to 100 Hz digital bandpass filter is applied with option *Normalize Locally* is enabled.

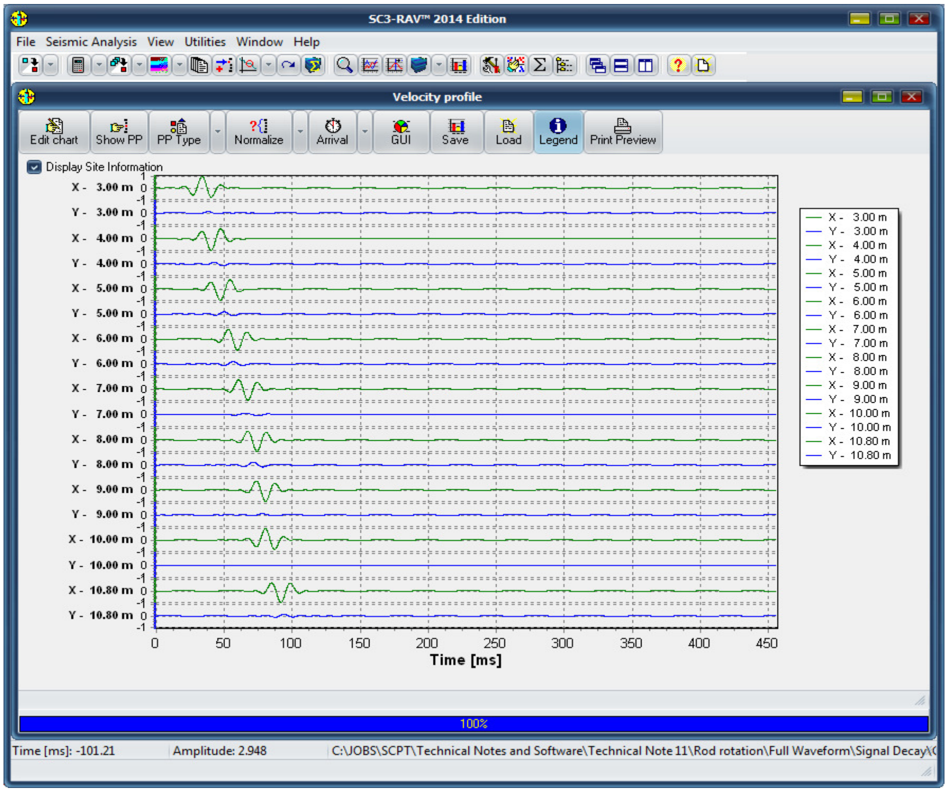

Figure 5. Data in Figure 4 after application of batch PHA and signal decay.

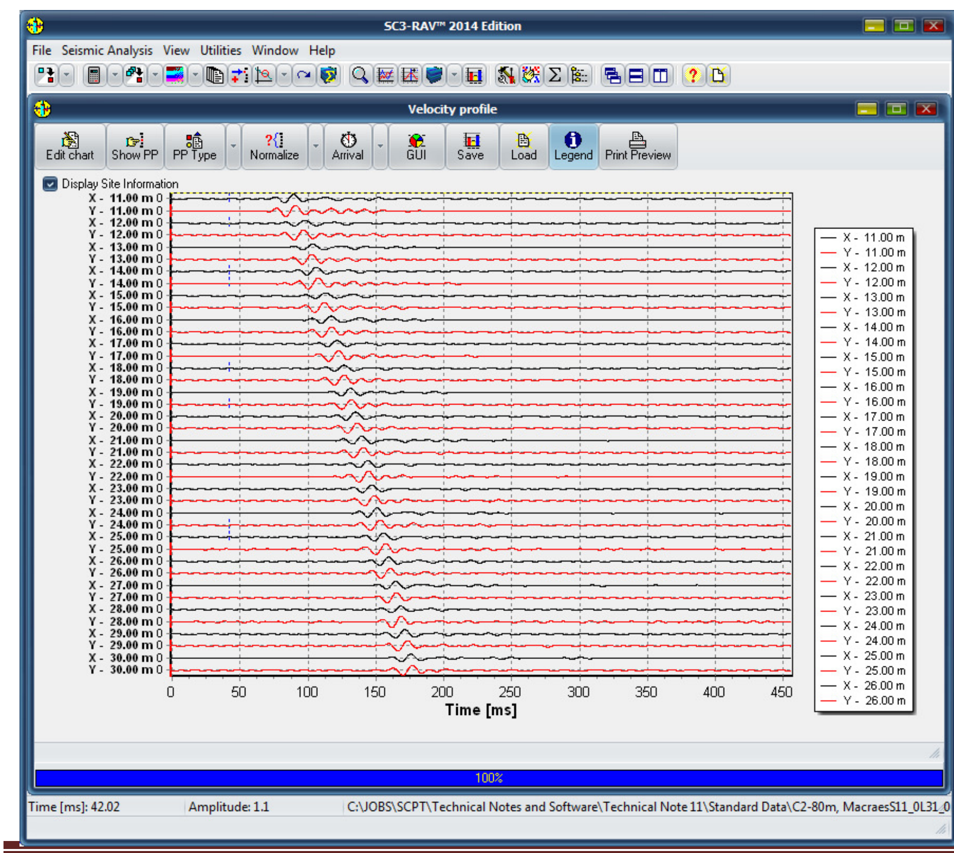

Figure 6. SH SCPT X and Y axis recordings (θ ≈ 45º in Figure 1) where a 30 Hz to 100 Hz digital bandpass filter is applied with option *Normalize Locally* is enabled.

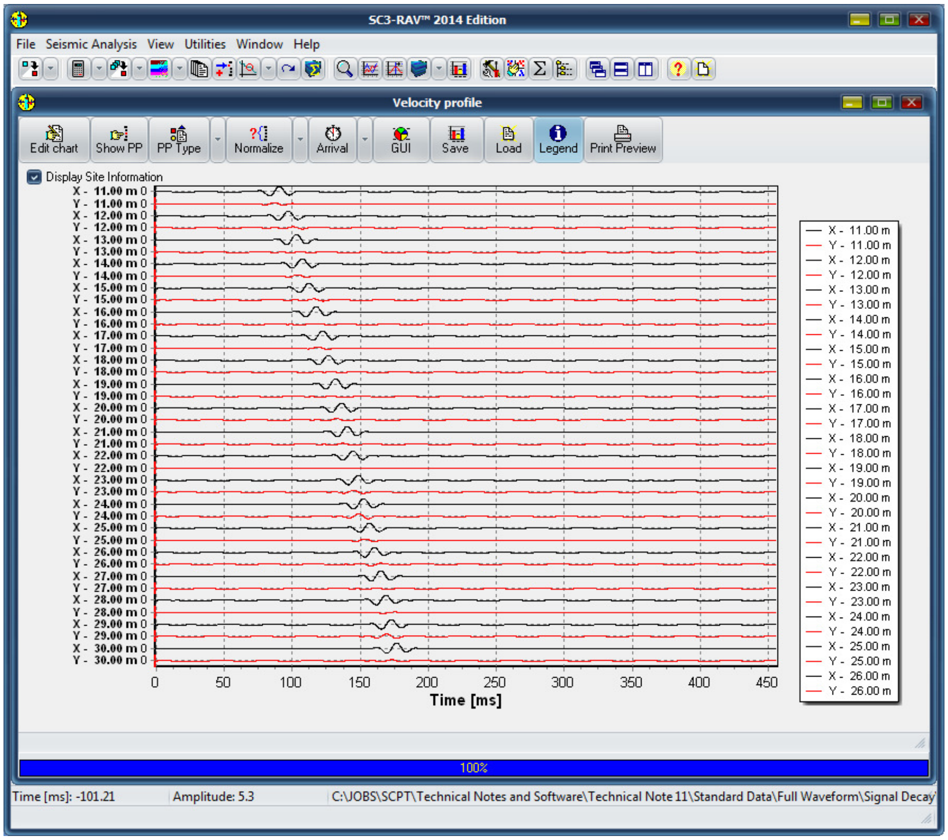

Figure 7. Data in Figure 6 after application of batch PHA and signal decay.

Erick Baziw
Gerald Verbeek

BCE's mission is to provide our clients around the world with state-of-the-art seismic data acquisition and analysis systems, which allow for better and faster diagnostics of the sub-surface. Please visit our website (www.bcengineers.com) or contact our offices for additional information:

e-mail: info@bcengineers.com

phone: Canada: (604) 733 4995 – USA: (903) 216 5372