Identifying the Water Table with DST P wave analysis

This purpose of technical note 38 is two-fold. 1) Outline the importance of taking raypath refraction into account when processing DST datasets. 2) Illustrates how the water table can be identified by DST data sets. Figure 1 below illustrates a Vertical Seismic Profile (VSP) of a recently acquired SCPT data set. The seismic traces illustrated in Fig. 1 have a 1200Hz low pass filter applied. Figure 2 illustrates the VSP of Fig. 1 where the P-wave (red lines) and SH-wave (green line) trending responses have been identified. Figure 2 also shows a reduction in P-wave amplitude from 5m to 6m (blue circle).

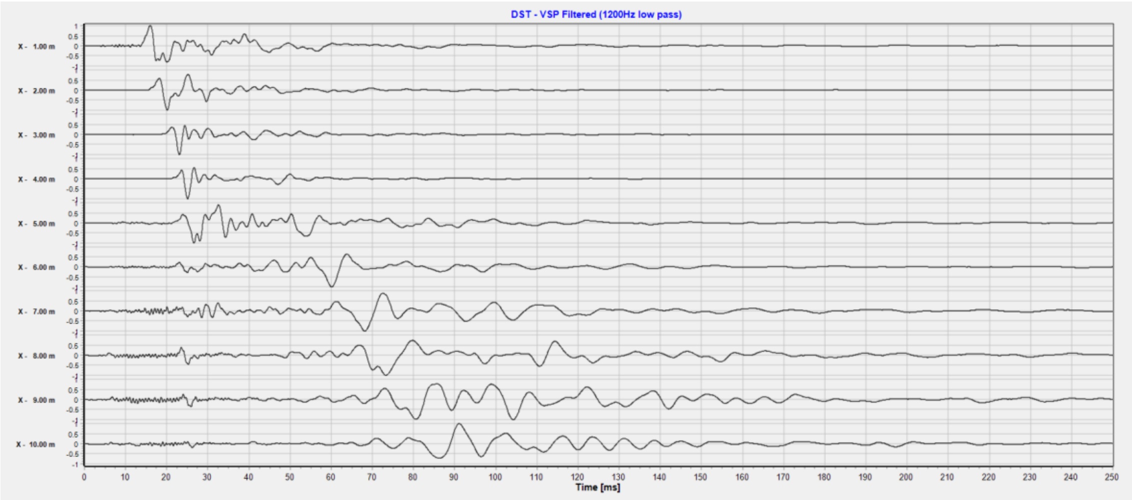

Figure 1. SCPT data set were a 1200Hz low pass filter was applied.

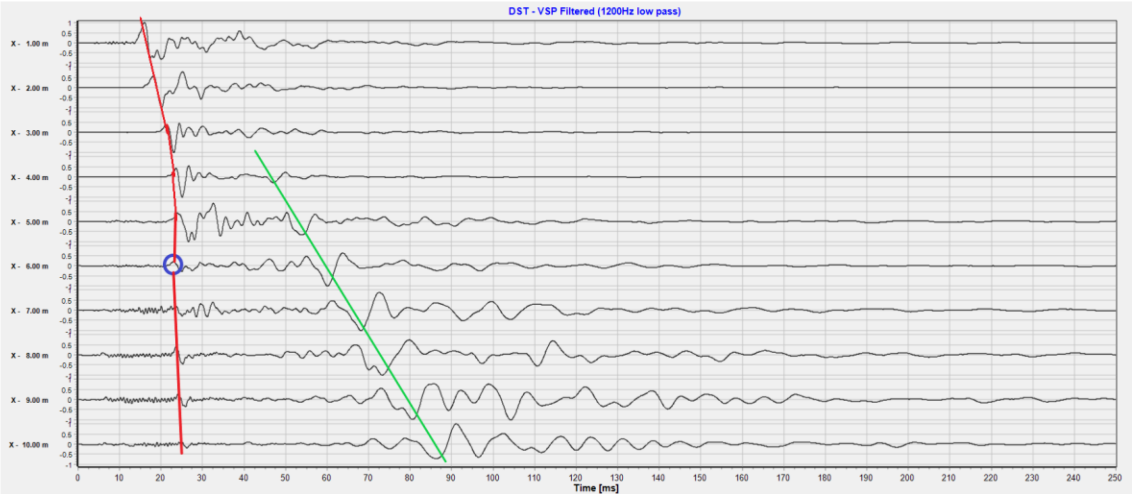

Figure 2. SCPT VSP of Fig. 1 where P-wave (red lines) and SH-wave trending responses (green line) are identified. There is an approximate 39% reduction in P-wave amplitude from 5m to 6m (blue circle).

Figure 3 displays the Peak Particle Accelerations (PPAs) for P-wave responses recorded at 5m and 6m. The amplitude is reduced by 39% from 5m to 6m based upon PPAs.

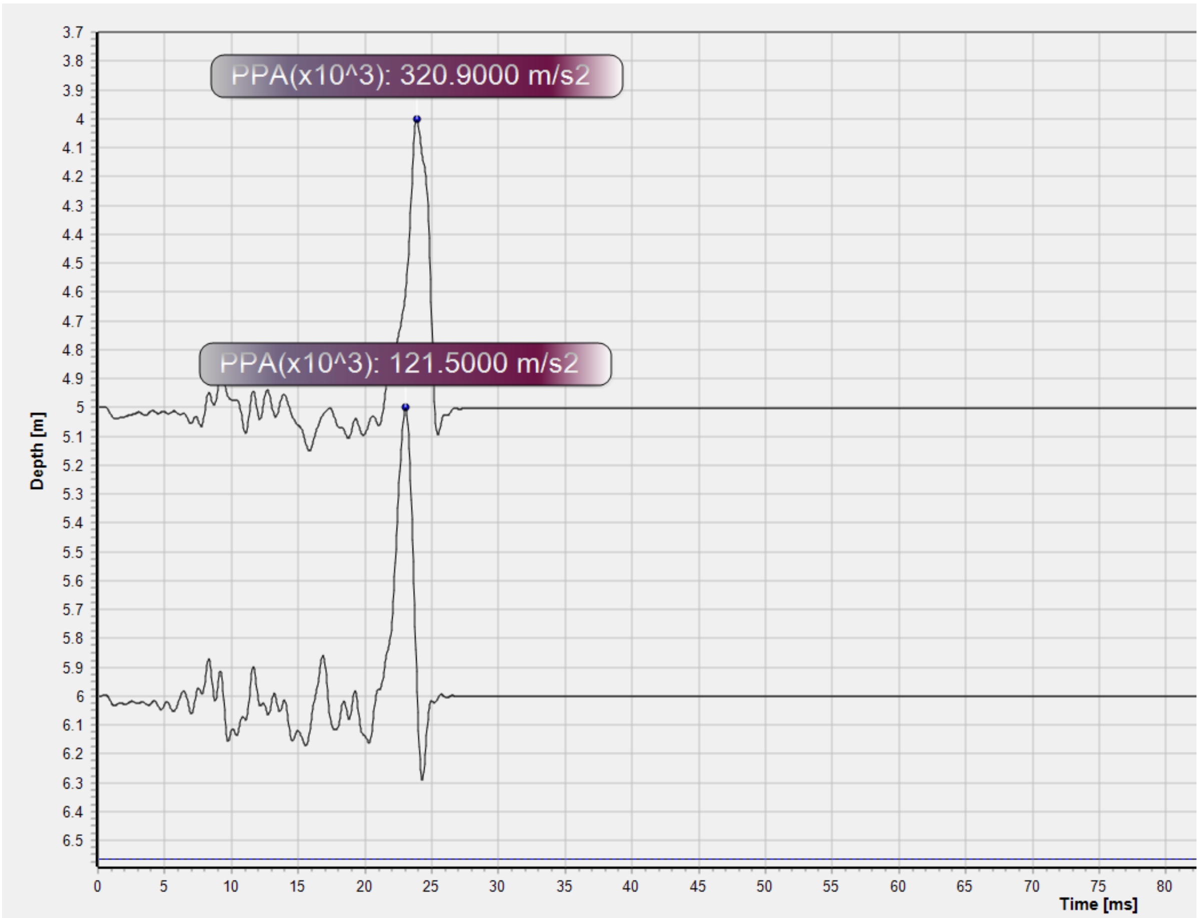

Figure 3. PPAs for P-wave responses at 5m and 6m. Amplitude reduction is 39%

Figure 4 illustrates the SCPT VSP of Fig. 1 where a 200Hz low pass filter was applied. The 200Hz filter increases the signal to noise ratio of the SH-wave responses as illustrated by the green trending line. Column 3 of Table 1 contains the estimated P-wave arrival times. Columns 4 and 5 of Table 1 outlined the estimated P-wave FMDSM interval velocity estimates and the straight ray interval velocity estimates, respectively, after processing the arrival times in column 3. Column 6 of Table 1 contains the FMDSM and straight ray P-wave interval velocity estimates percent differences. As is evident from column 6, there are very large percent differences. These large percent differences indicate that the straight ray interval velocity estimates for this set of P-wave data are nonsensical and cannot be relied upon. Column 2 of Table 1 contain the FMDSM estimated SH-wave velocities. Figure 5 illustrates the source wave raypaths generated from the output of the FMDSM algorithm after processing the arrival times given in Table 1.

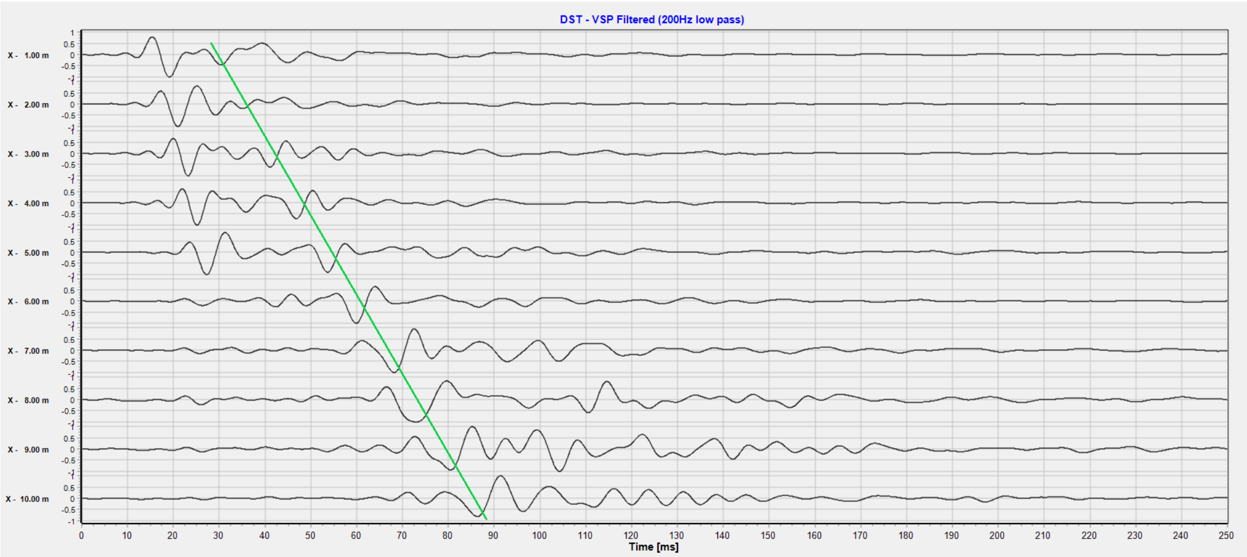

Figure 4. SCPT VSP of Fig. 1 with 200Hz low pass filter and SH-wave responses by green trending line.

Table 1. Estimated P-wave arrival times, P-wave FMDSM interval velocity estimates and straight ray interval velocity estimates, and FMDSM and straight ray P-wave velocity percent differences.

Depth [m]	SH-Wave FMDSM Interval Velocity [m/s]	P-Wave Arrival Time [ms]	P-Wave FMDSM Interval Velocity [m/s]	P-Wave Straight Ray Interval Velocity [m/s]	Percent Difference [%]
1	106.1	13	200	200	N/A
2	107.6	15.1713	212.1	241.4	12.9
3	114.4	18.3087	218.2	228.8	4.7
4	130.8	20.4501	302.5	384.3	23.8
5	125	21.2469	545.3	1106.2	67.9
6	141.8	21.0	1447.3	-3710.1	455.8
7	113.8	21.4	1549.9	2344.5	40.8
8	174.4	21.9	1574.1	1904.5	19.0
9	134.9	22.4	1694	1924.5	12.7
10	162.1	23.1	1777.4	1384.9	24.8

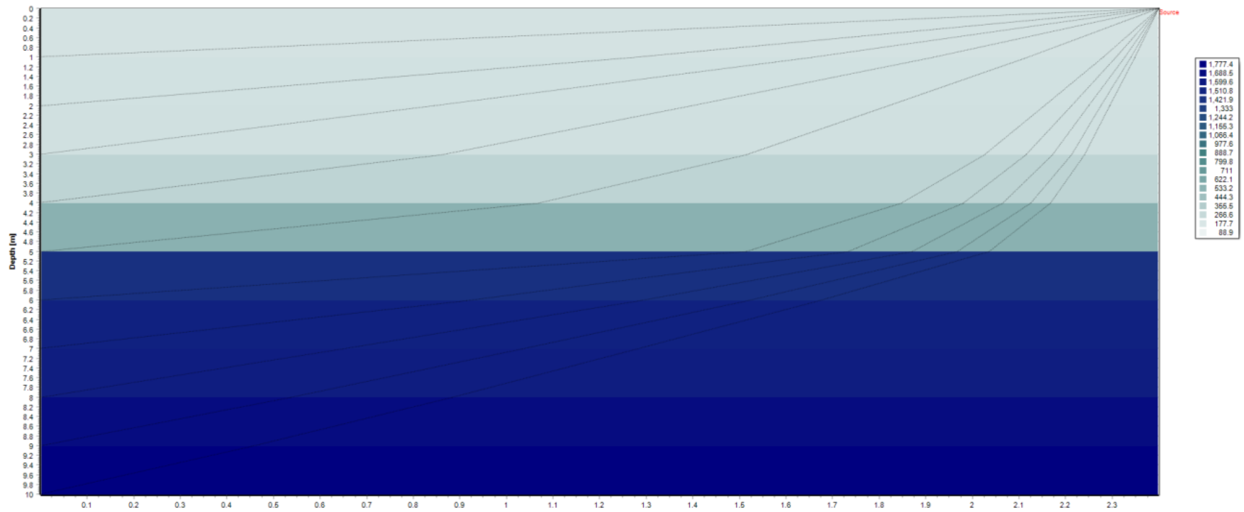

Figure 5. FMDSM output after processing the P-wave arrival times shown in Table 1.

Figure 6 outlines typical P-wave and S-wave velocities for varying soil types. As is shown in Fig. 6, there can very low P-wave velocities for dry soils of variable type and age. This is consistent with the results outlined in Table 1 (columns 2 and 4) for depths 1m to 5m. When the soil becomes saturated (at water table) it is expected that the P-wave velocity becomes close to or exceeds the P-wave velocity in water (1400m/s to 1600m/s). In Table Column 6 there is a large jump in P-wave velocity from 5m (545.3m/s) to 6m (1447.3 m/s); therefore, it is expected that the water table resides between 5m and 6m.

Another indication of the P-wave impacting on the water table is a significant reduction in the source wave amplitude. This is due to the significant contrast between the unsaturated P-wave velocity layer (545.3 m/s) and the saturated layer (1447.3 m/s). The transmission coefficient for the P-wave (ignoring mode conversion from P to SV wave) is given by eq. (1)

$$T_{56} = \frac{A_6}{A_5} = \frac{2\rho_5 V_5 cos\theta_5}{\rho_5 V_5 cos\theta_5 + \rho_6 V_6 cos\theta_6} \tag{1}$$

In eq. (1) $V_5 = 545.3\ m/s$ and $V_6 = 1447.3\ m/s$. From the FMDSM raypath we get $\theta_5 = 20°$ (incident angle) and $\theta_6 = 56°$ (angle of refraction). We assume that $\rho_5 = 0.75\rho_6$. Substituting these values in eq. (1) gives $T_{56} = 0.64$; therefore, the amplitude reduction due to the transmission coefficient is 64%. This calculated amplitude reduction is reasonable considering the estimated amplitude reduction determined by calculating the P-wave PPAs between 5m and 6m is 39%. The P-wave amplitude is also attenuated due to absorption, geometric spreading (≈15%) and mode conversion from P to SV wave (accounting for 25% reduction difference). The water table was determined to be at approximately 5.5m from CPTU data. This is very close to the P-wave analysis estimation.

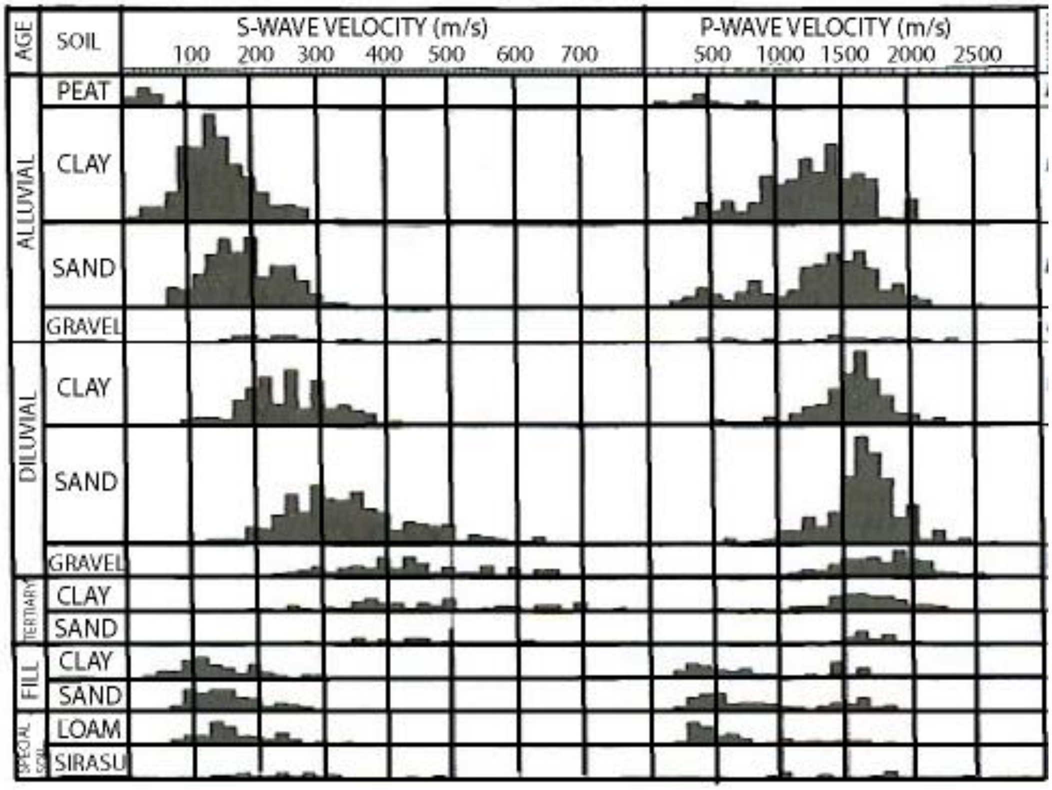

Figure 5. Distributions of P- and S-wave velocities (Imai and Tonouchi (1982))

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