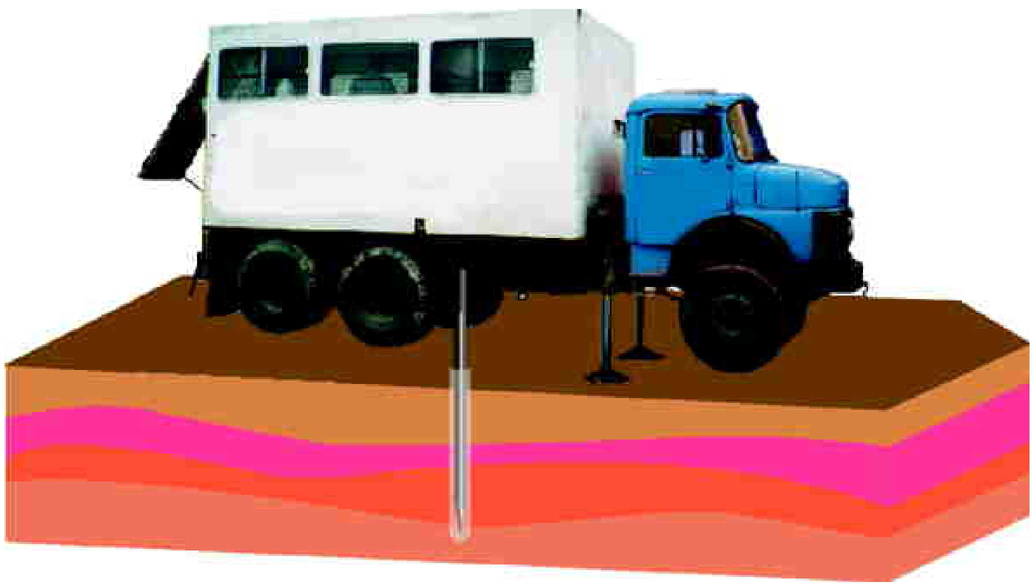
Terratek



Piezocone tests

Test standards and procedures

Seismic piezocone

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SCOPE

This document describes equipment and procedures for carrying out site investigation through CPTU and seismic CPT. It also discusses de advantages of seismic CPT in relation to cross-hole tests.

CPT STANDARDS

Terratek carries out piezocone tests according to the following standards:

1. ASTM D5778 (2000) Standard method for performing electronic friction cone and piezocone penetration testing of soils

2. ISSMFE Report TC 16 - International reference test procedures for cone penetration tests

3. ABNT NBR 12069 - Solo - ensaio de penetração de cone in situ (CPT);

EQUIPMENT AND PROCEDURES

Piezocone (CPTU)

The piezocone is a standard 10 cm^2 cross-sectional area electronic instrument, 100 MPa maximum tip resistance (Figure 1). Terratek also uses a 10 MPa "research" piezocone for testing very soft soils. However this tool should be regarded as a research equipment that has to be used with extreme care, as it can be easily damaged if harder materials are struck during penetration.

Figure 1 Details of the seismic piezocone

All Terratek's cones are 36 mm in diameter and apex angle of 60 degrees. Just above the tip there is 150 cm^2 area friction sleeve. The porepressures are measured at a porous element just above the tip, corresponding to position u_2, according to the nomenclature adopted by Robertson and Campanella (1989).

Above the cone there is a geophone, capable of sensing seismic waves generated at the ground surface.

An electronic package carried by the cone conditions and amplifies all electrical signals and sends them through an electrical cable to the data acquisition system at the surface.

The tests are carried out from a site investigation truck (Figure 2) capable of applying 200 kN force on the steel rods.

Figure 2 Site investigation truck

The test is stopped if one of the following conditions is reached:

- Tip resistance limit of 100 MPa;
- Load capacity of the hydraulic system;
- Excessive inclination of the cone, which would lead to damaging the cone or rods.

Cone penetration is measured from the ground surface through a depth encoder driven by rod penetration.

The data acquisition system (Figure 3) is a PC based equipment with a 16 bit resolution. The software records, displays on the screen and saves in the hard disk the following measurements:

- Depth (m);
- Tip resistance (q_c);
- Local unit friction (f_s);
- Porepressure above the cone (u_2);
- Cone inclination in degrees.

When rods are added, the penetration stops and the system automatically goes to dissipation mode, when porepressures are recorded with time. The screen display changes to porepressure versus square root of time in seconds.

Figure 3 Seismic piezocone data acquisition system

SEISMIC TESTING AND DATA PROCESSING

Seismic piezocone tests yield a shear wave velocity profile and the shear modulus G_{max} or G_0 at small (micro) strains. Terratek's piezocone is a standard electric cone with a small geophone mounted at the top. This sensor enables the detection of the arrival of shear waves.

Figure 4 and Figure 5 show how shear or *S* waves are generated at the soil surface by striking a steel plate with a hammer. The steel plate should be securely fixed on the soil surface by a weight or other method. The hammer is electrically connected to a triggering circuit in the data acquisition system.

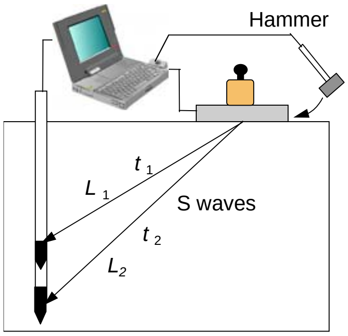

Figure 4 Seismic test

Figure 5 Generating shear waves at the ground surface

The seismic test is normally carried out during cone penetration pauses to add new rod lengths. As the cone is at depth z_i, the strike plate is hit by the hammer (Figure 5) and the triggering circuit starts the data acquisition. A signal versus time is obtained at each test depth z_i and corresponds to the arrival time t_i of the shear wave.

Terratek's procedure is to acquire at least data from three strikes at each level to obtain a mean shear wave velocity profile (V_s).

The shear modulus G_{max} is then computed by:

$$G_{max} = \frac{\gamma}{g} \cdot V_s^2$$

where γ is the soil unit weight and g is the acceleration of gravity.

Small strain G_{max} values can be corrected to the macro-strain domain, which corresponds to most geotechnical engineering applications by the use of a single laboratory test or theoretical degradation curves.

Terratek processes seismic data through its proprietary PC program *Spas* (*Signal processing and analysis software*) using digital signal analysis techniques in the frequency domain. Bucher et al (1999) describe the cross-correlation analysis employed in *Spas*.

Dissipation tests

When penetration stops the system enters automatically in dissipation mode in which porepressures (u) are observed with elapsed time (t). The porepressures are plotted as a function of $\sqrt{t}$. The graphical technique suggested by Robertson and Campanella (1989), yields a value for t_{50}, which corresponds to the time for 50% consolidation.

The value of the coefficient of consolidation in the radial or horizontal direction c_h was then calculated by Houlsby and Teh's (1988) theory using the following equation:

$$c_h = \frac{Tr^2 I_r^{0.5}}{t_{50}}$$

where:

T = time factor given by Houlsby and Teh's (1988) theory;

r = piezocone radius;

I_r = stiffness index, equal to G divided by the undrained strength of clay (c_u). This index was taken as 100.

t_{50} = time corresponding to 50% consolidation

A value of permeability was, then, estimated from c_h taking into account soil modulus *M* from seismic tests.

CPT DATA ANALYSIS

Terratek processes and interprets CPTUS data through specific software: Figure 6 presents an example of an interpreted CPTU log which plots the following data:

- * Tip resistance (corrected for unequal cone ends q_t (MPa);
- * Friction ratio, $R_f = f_s / q_t$ (%);
- * Porepressures: measured by the piezocone (u_2) and hydrostatic (u_0), (kPa);
- * Stratigraphy interpretation, according to the SBT Soil Behaviour Type method (Robertson, 2009)

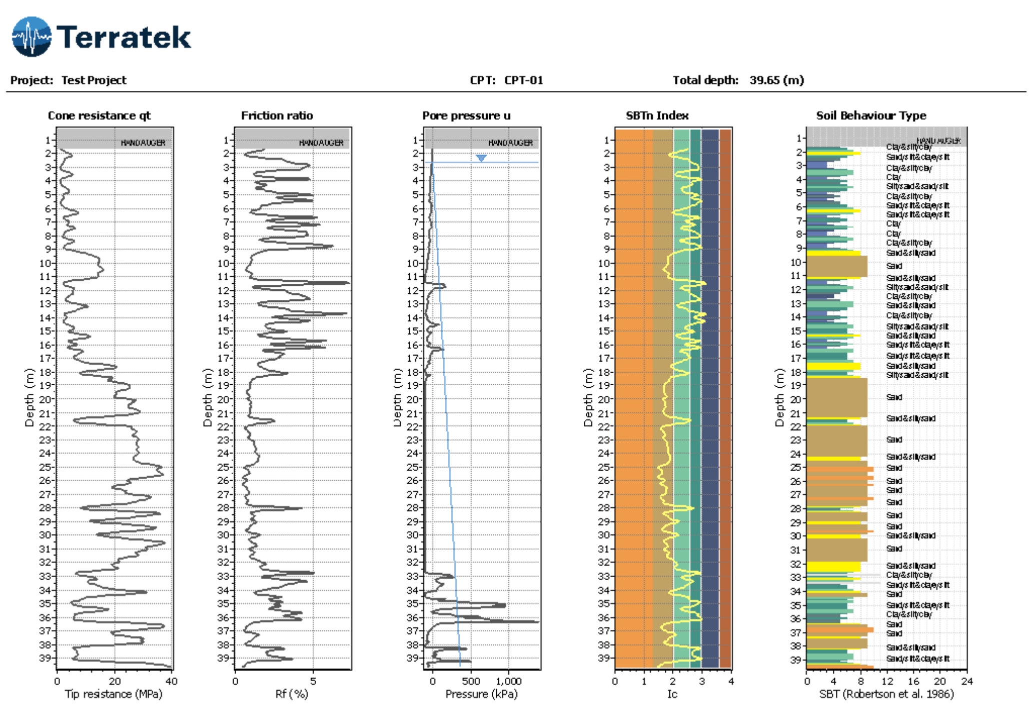

Figure 6 Example of a CPTU log

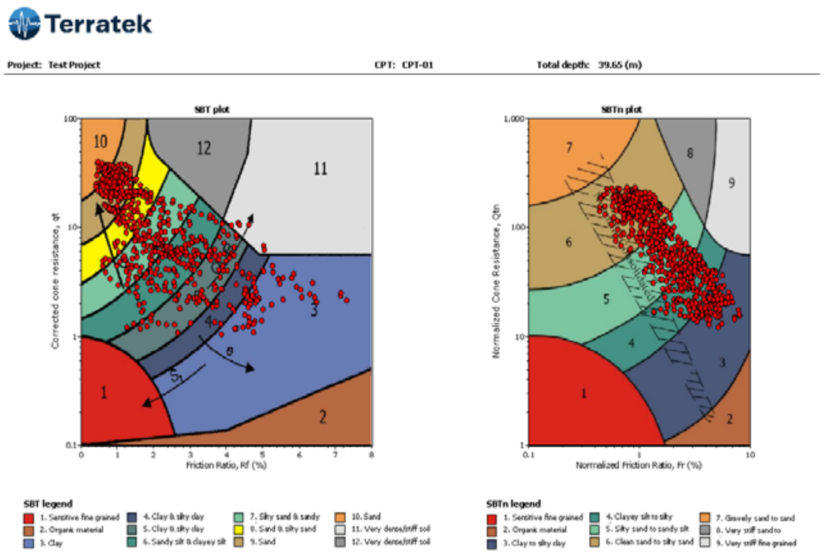

Figure 7 Example of a SBT soil classification

Processing shear wave velocity signals

Terratek uses a proprietary software Spas (*Seismic Processing and Analysis of Signals*). The first stage in signal processing is a check on signal repeatability. This is carried out by visual inspection of all signals at a time in the time and frequency domain. *Spas* enables the user to select a depth (on the left side of Figure 8. The upper plot of the same figure displays the signal in time domain. *Spas* automatically generates a signal plot in frequency domain through a Fast Fourier Transform (FFT) transformation. The user can decide whether to keep or to delete one or more signals.

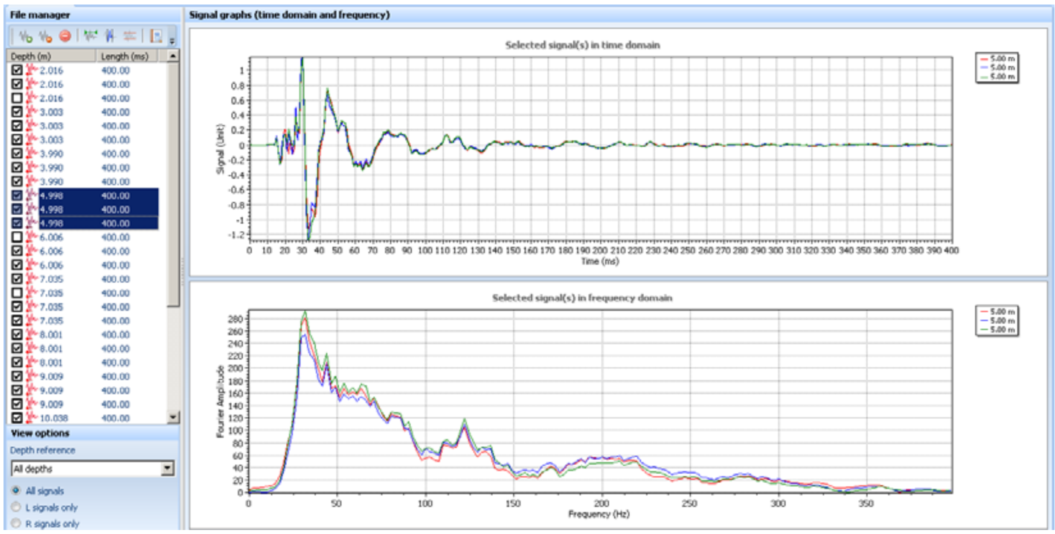

Figure 8 Visual inspection of one single signal

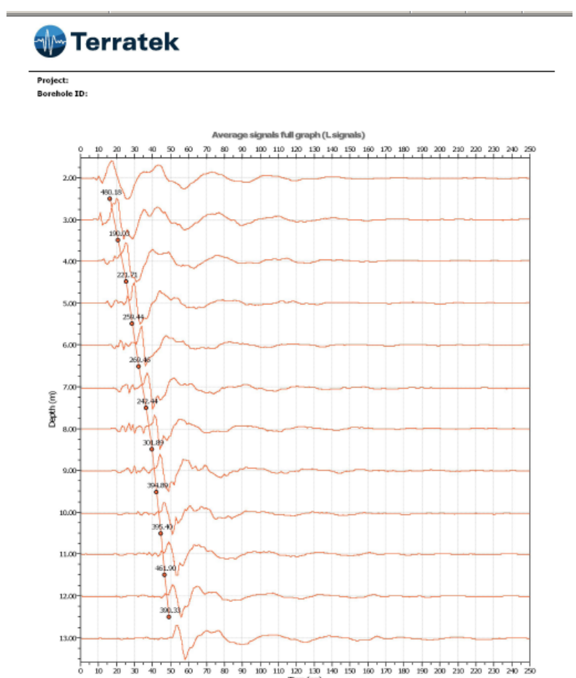

Figure 9 Transit time analysis

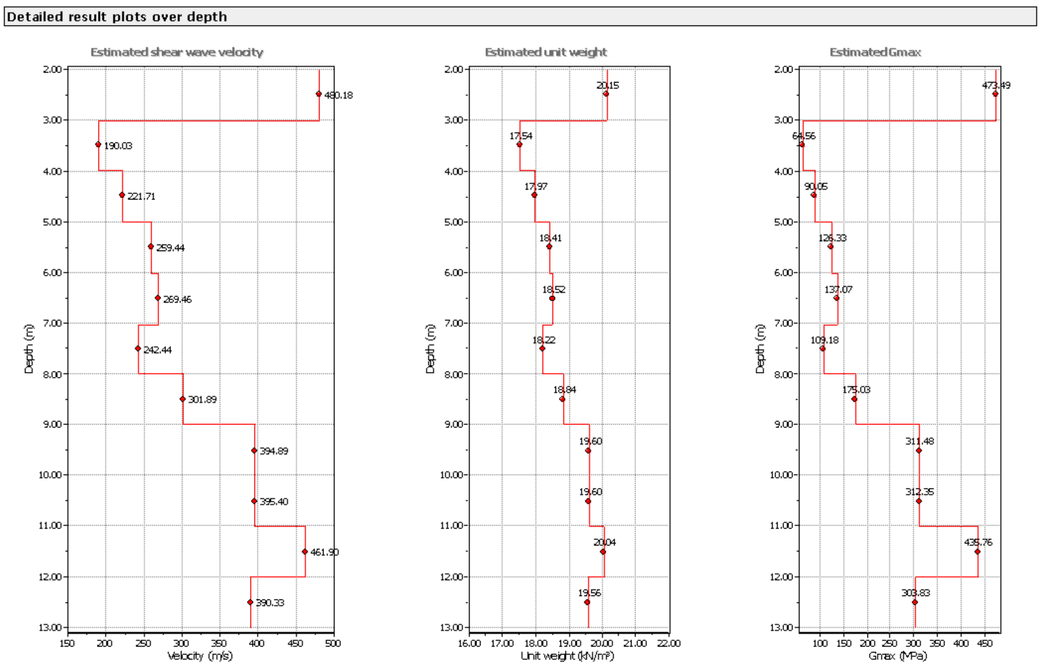

Figure 10 Sample seismic piezocone test results showing the shear wave velocity, the shear modulus and a tip resistance plot against depth

PIEZOCONE CALIBRATION

Terratek's cones are calibrated before and after each job in our laboratory following ASTM D5778 standard. The tip and friction sleeve sensors are calibrated against a precision electrical load cell. The porepressure transducer is calibrated against a bourdon type gauge.

Figure 11 Calibration loading frame

Piezocone calibration

Terratek

Tip resistance

Cone tip capacity 100 MPa	Cone diameter 36 mm	Calibrated by	DHBS
Date: 18 Nov 2006	Cone area 10 cm^2	Friction capacity 1000 kPa	
Calibration standard ASTM D5778	Cone serial number 302	Sleeve area 150 cm^2	

Target gauge reading	Actual gauge reading	Applied force	Full scale output FSO	Measured cone resistance	Measured sleeve resistance	Actual cone resistance	Best straight line fit	Linearity	Calibration error
		x		y		q_{ca}	y'=mx+b	(y-')/FSO	$(q_{ca}$-y') / q_{ca}
		kN	FSO - %	q_c (MPa)	f_s - kPa	MPa	MPa	%FSO	%MO
0	Baseline			0.053	2.057				
0	0	0.0	0.0	0.000	2.057	0.000	-0.052	0.052	
200	200	2.0	2.0	2.037	3.147	1.961	1.909	0.128	
500	500	4.9	4.9	4.912	4.004	4.903	4.851	0.061	1.063
1000	1000	9.8	9.7	9.736	6.128	9.807	9.754	-0.018	0.533
2500	2500	24.5	24.2	24.245	10.877	24.517	24.464	-0.218	0.215
5000	5000	49.0	48.8	48.765	13.877	49.033	48.979	-0.215	0.109
7500	7500	73.5	73.7	73.706	16.381	73.550	73.495	0.211	0.074
0	0	0.0	0.0	0.002	2.213	0.000	-0.052	0.054	
0	Baseline			0.055	2.213				

Calibration results		Results	Unit	Allowable	Approval
***Best fit straight line (y'=mx+b)**	**m =**	1.000			
	b =	-0.052			
Maxmum load transfer sleeve		1.638	%FSO	2	yes
Max linearuty error		-0.218	%FSO	1	yes
Max calibration erros		1.063	%MO	2%MO>20%FSO	yes
Max zero load error		-0.002	%FSO	0.5	yes
Max sleeve zero drift error		-0.016	%FSO	1	yes

Figure 12 Calibration results

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