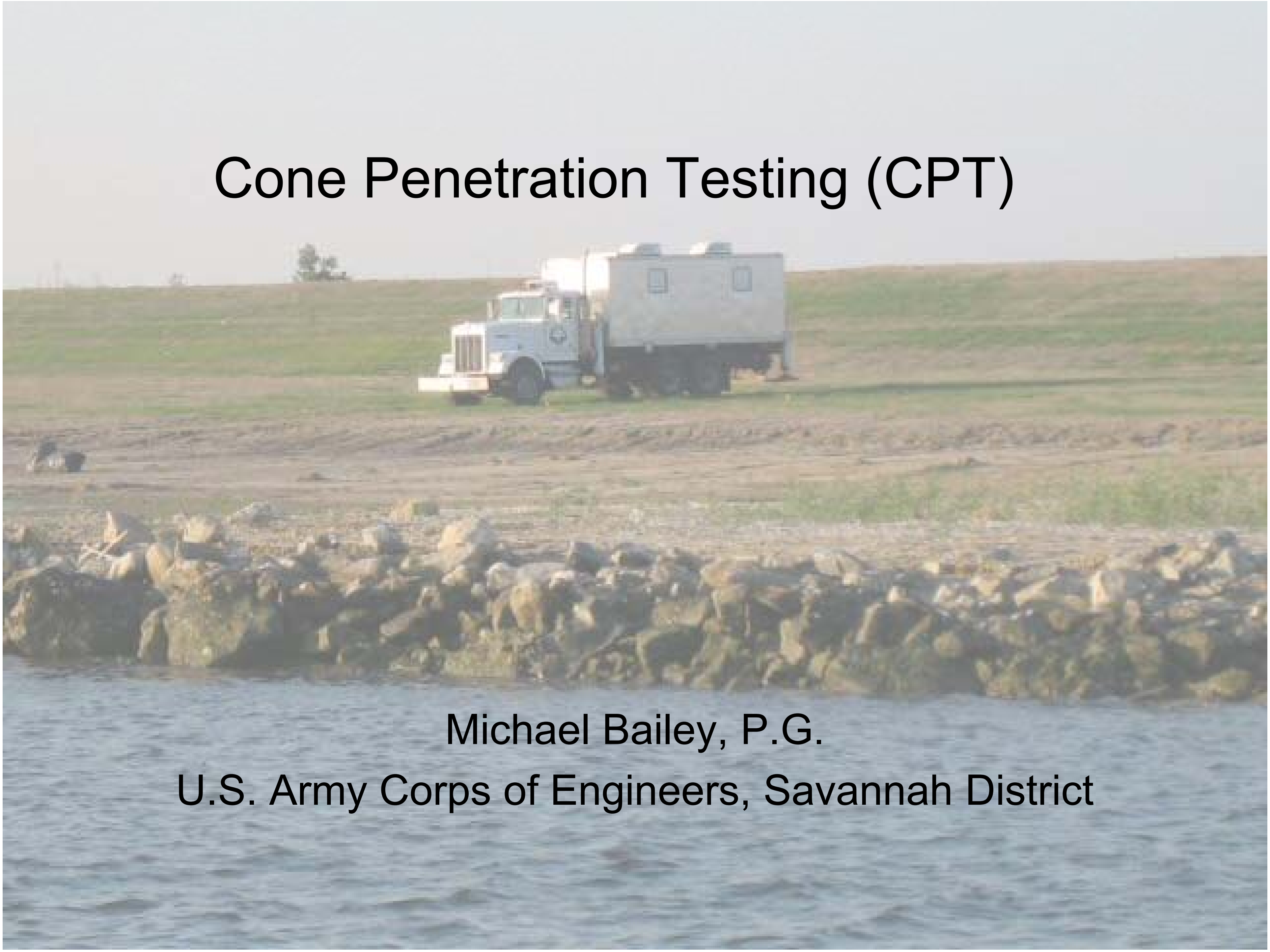


Cone Penetration Testing (CPT)

Michael Bailey, P.G.
U.S. Army Corps of Engineers, Savannah District

Recommended publications

- ASTM D 5778-07 *Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils*

    Recently updated standard describing state-of-the-practice equipment and procedures. Comprehensive guidance for operation and maintenance of CPT equipment.

- Lunne, T., Robertson, P.K. and Powell, J.J.M. (1997), *Cone Penetration Testing in Geotechnical Practice*, Blackie Academic/Routledge Publishing, New York.

    Thorough introduction to CPT history, theory and applications. Considered an essential resource by many CPT practitioners.

NCHRP
SYNTHESIS 368

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Cone Penetration Testing

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 368

Cone Penetration Testing

A Synthesis of Highway Practice

CONSULTANT
PAUL W. MAYNE
Georgia Institute of Technology
Atlanta, Georgia

SUBJECT AREAS
Soils, Geology, and Foundations

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2007
www.TRB.org

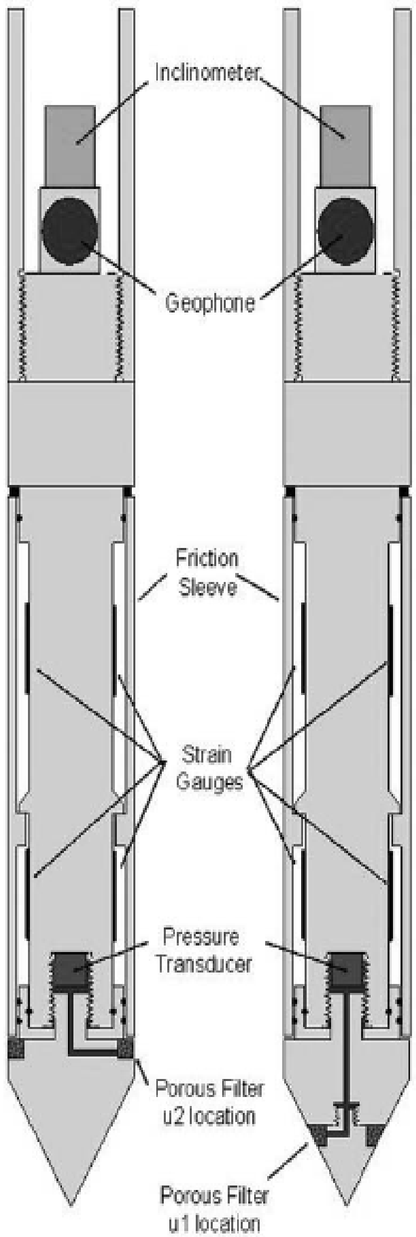
Traditional geotechnical soils investigations

- Drill rigs used to collect SPT or “undisturbed” samples.
- Inconsistencies in sampling methodologies are common.
- Disturbance of “undisturbed” samples is unavoidable and can compromise sample integrity.
- Many opportunities to introduce error from sampling techniques to sample transport to laboratory extraction, handling and testing procedures.
- Cost, $12 to $24 per foot (NCHRP findings), may be prohibitively expensive for detailed site investigations. Does not include laboratory testing costs.
- Relatively time consuming to collect samples.
- Spoils from drilling can create additional problems.

- Main advantage – physical sample is collected.

CPT investigations

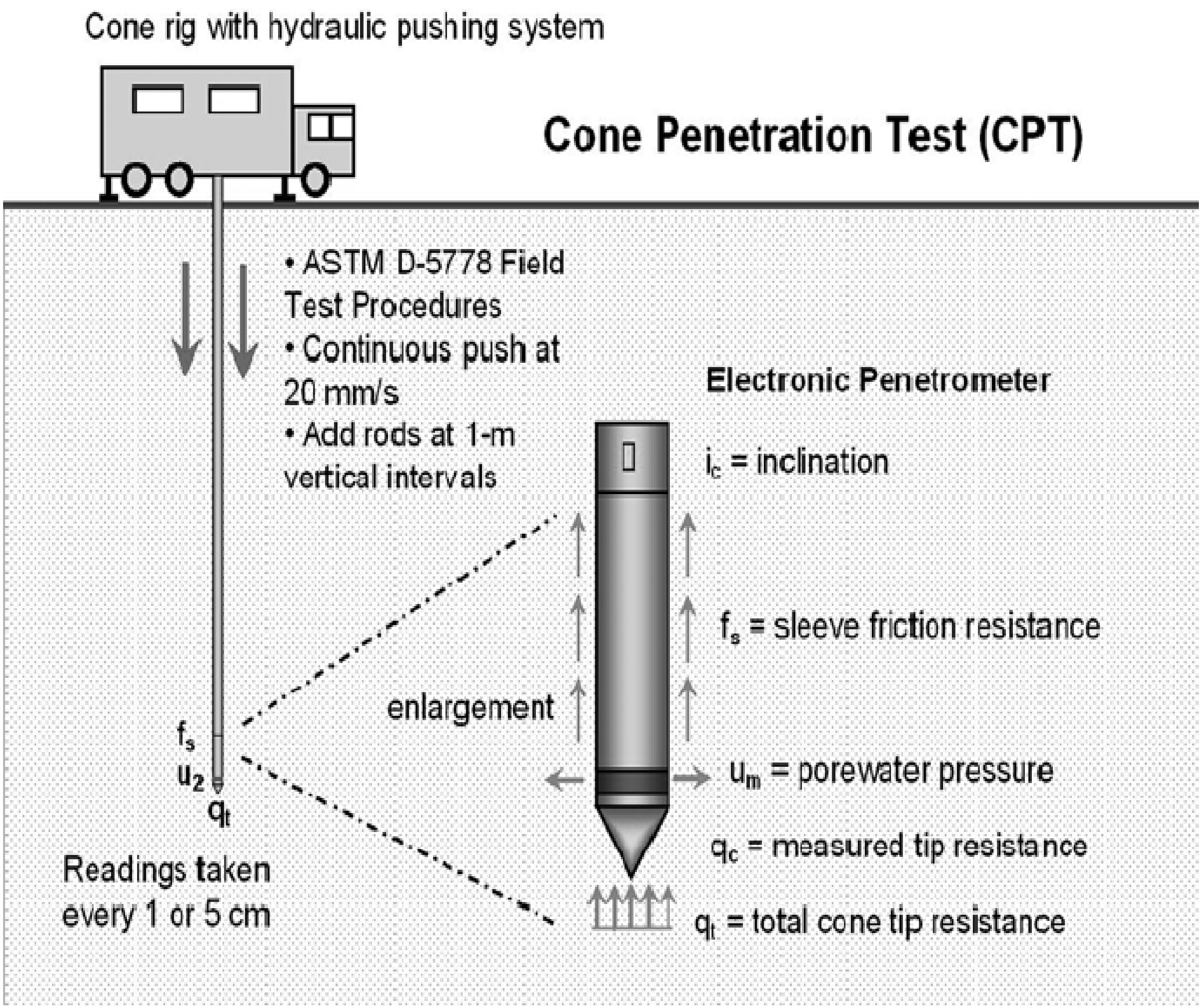

E4FCS
CLAMP
ON
OFF
UNCLAMP
VERTEK



Source: NCHRP Synthesis 368

- Standard cone dimensions: tip 10 cm^2, sleeve 150 cm^2, 1.44-inch diameter
- Another common configuration: tip 15 cm^2, sleeve 225 cm^2, 1.75-inch diameter
- 5, 10, 15-ton load capacity cones most common

- Tip resistance (q_c)
- Sleeve friction (f_s)
- Induced pore pressure and pore pressure dissipation ($U_{1,2,3}$)
- Shear wave velocity
- Soil resistivity
- Inclination
- Temperature



Source: NCHRP Synthesis 368

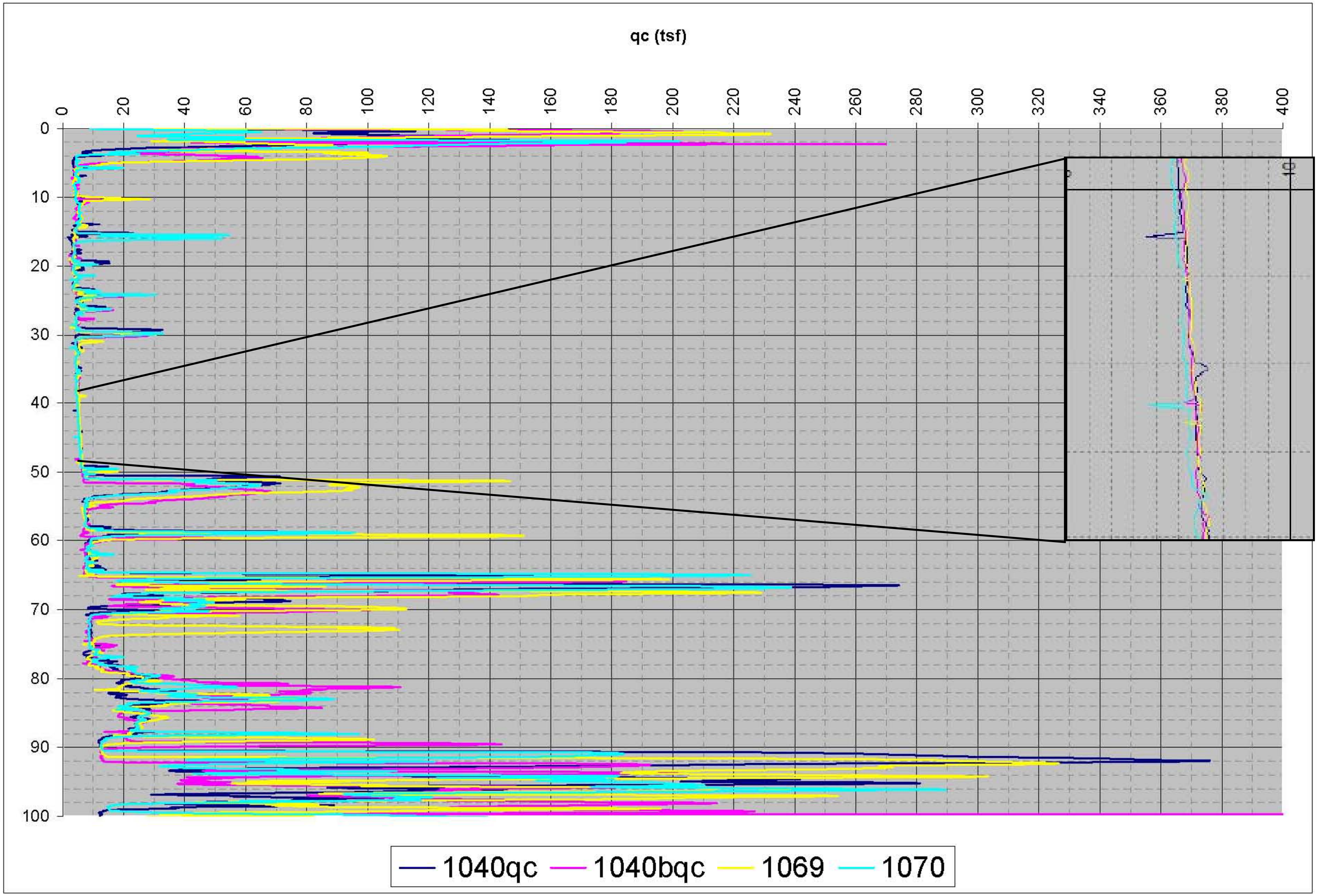
- CPT - Continuous sampling, 1cm vertical resolution.
- Conservatively, 5 times faster than traditional drilling.
- $6 to $9 per foot (NHCRP findings).
- Superior accuracy and precision compared to typical drilling and testing.
- Predicts many design parameters normally obtained by traditional drilling and sample testing.
- Laboratory sampling requirements are greatly reduced for added cost savings.
- No drilling spoils are generated.
- Does not eliminate the need for drilling and testing, but can greatly reduce number of borings/samples.
- Can collect additional data such as soil resistivity and shear wave velocity with little added cost.

- Disadvantage – physical soil sample is generally not collected. Only used in unconsolidated sediments.

Accuracy and precision

- Accuracy expressed as calibration non-linearity of strain gauges.
- Typically 0.2 % of the full scale output (q_c and f_s) and 0.5 % of full scale for pore pressure.

- Precision is one of the hallmarks of CPT. Considering strata heterogeneity, remarkable repeatability is achieved in side-by-side comparison soundings.
- Precision of the tip readings is most reliable. Tip readings generally have the greatest design significance.



qc (tsf)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
0
10
20
30
40
50
60
70
80
90
100
1040qc
1040bqc
1069
1070

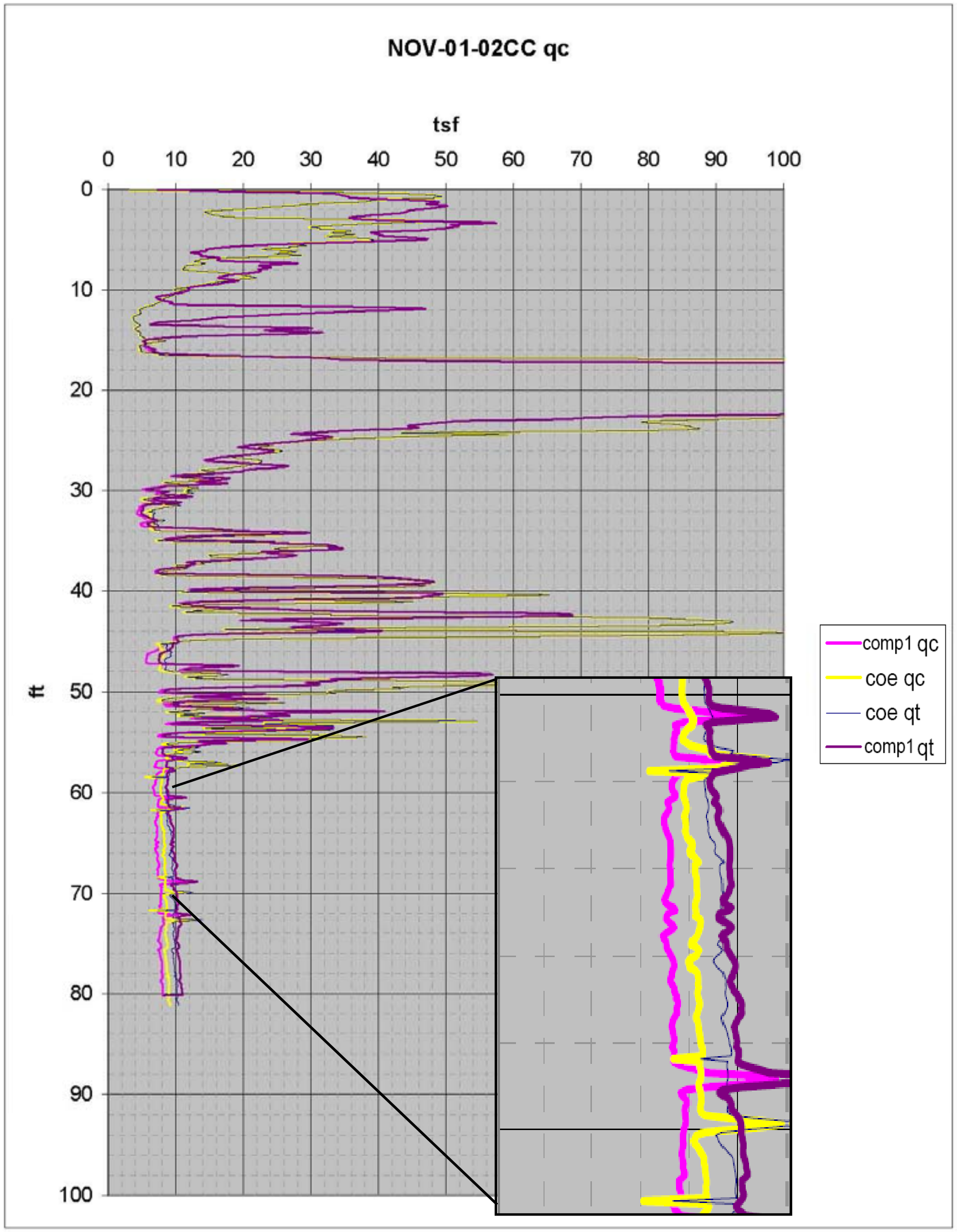
Interpreting results

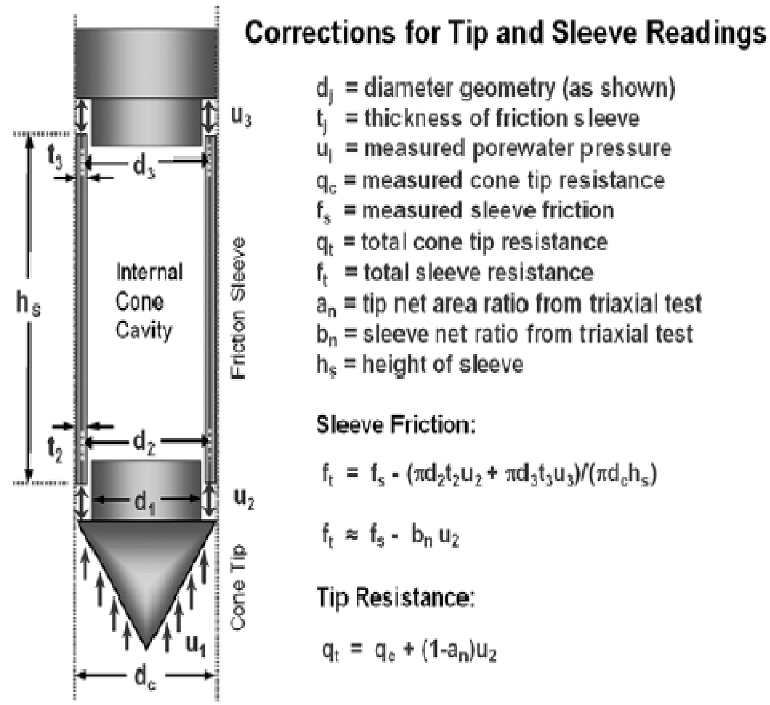
- When pore pressure is collected, referred to as piezocone or CPTu sounding. Three basic measurements q_c, f_s, u_2.
- q_c is typically corrected for pore pressure effects (q_t).
- $q_t = q_c + u_2(1\text{-}a)$, where a is net area ratio of tip, ranges from 0.6 to 0.8 depending on probe design.
- Normalization for overburden stress.

$Q_t = (q_t\text{-}\sigma_{vo})/\sigma'_{vo}$

$Fr = 100\%[f_s/(qt\text{-}\sigma_{vo})]$

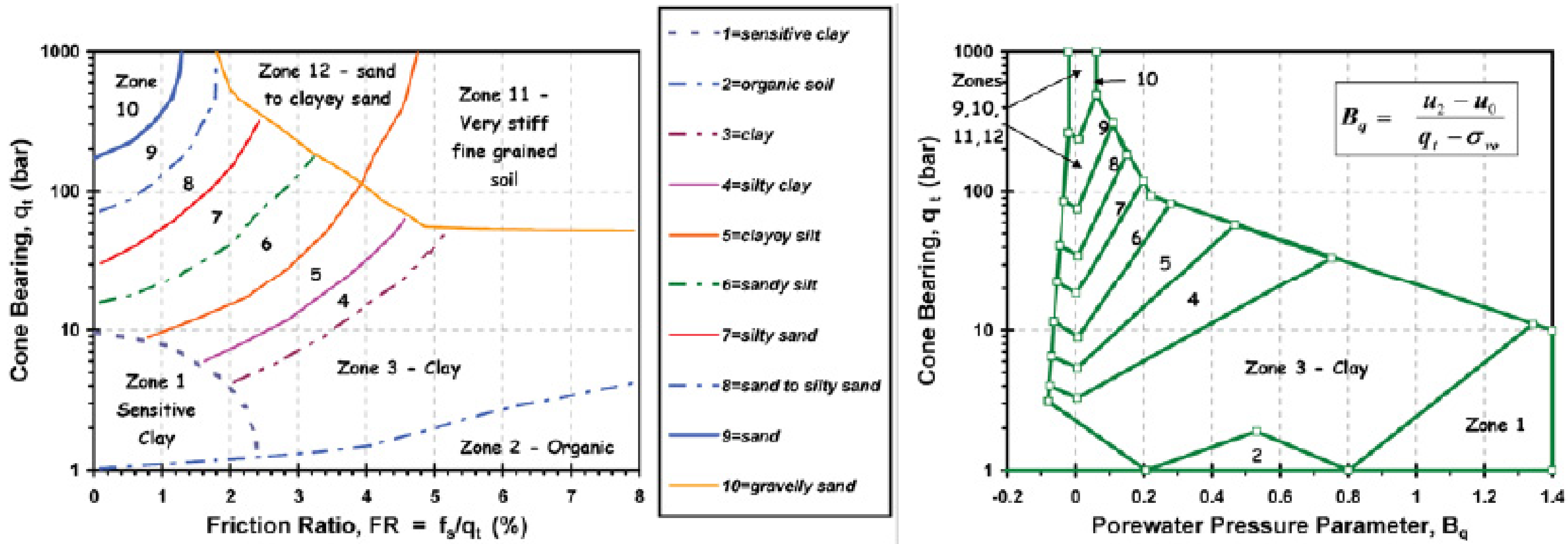
$B_q = (u_2\text{-}u_0)/(q_t\text{-}\sigma_{vo})$ = pore pressure parameter



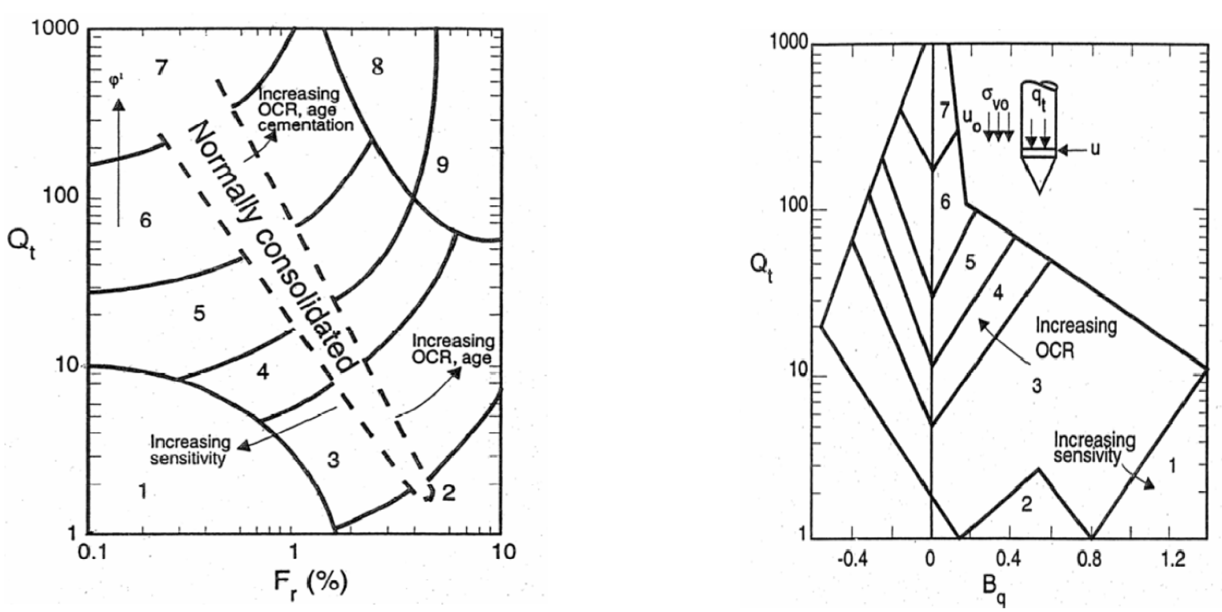


Source: NCHRP Synthesis 368 (aftter Jamiolkowski et al. 1985)

Soil behavior type (SBT)



Source: NCHRP Synthesis 368 (after Robertson et al. 1986)

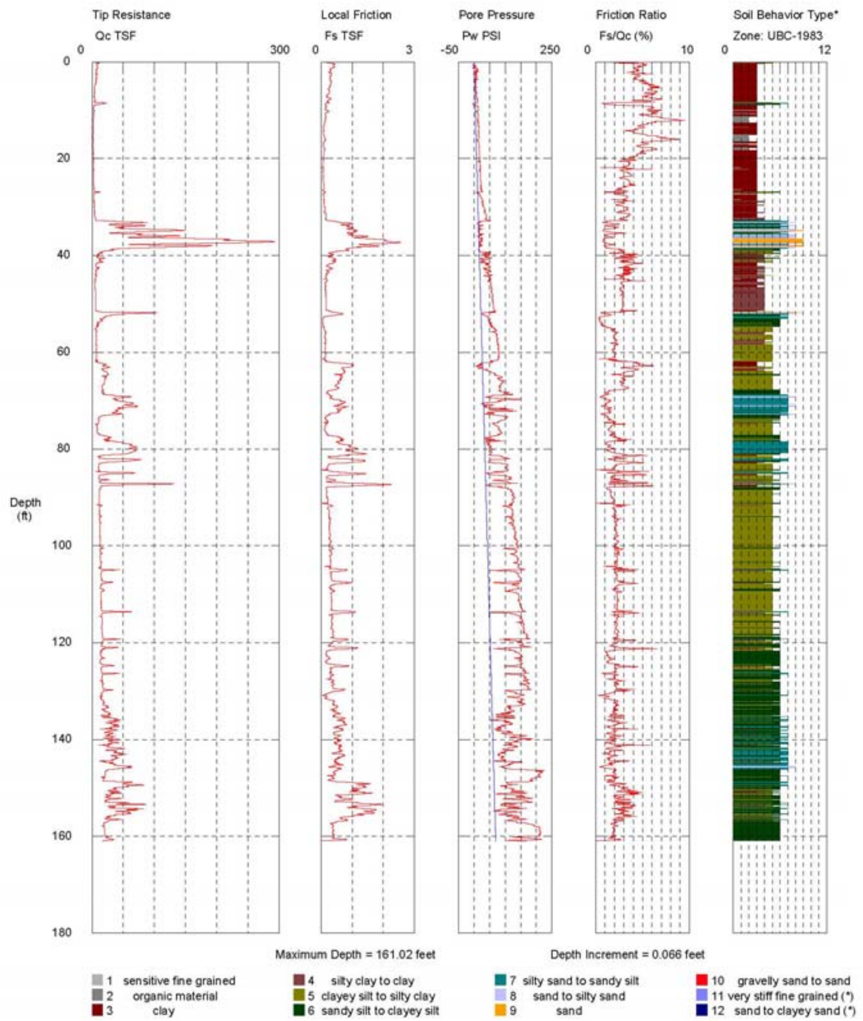


Source: Robertson and Campanella 1990

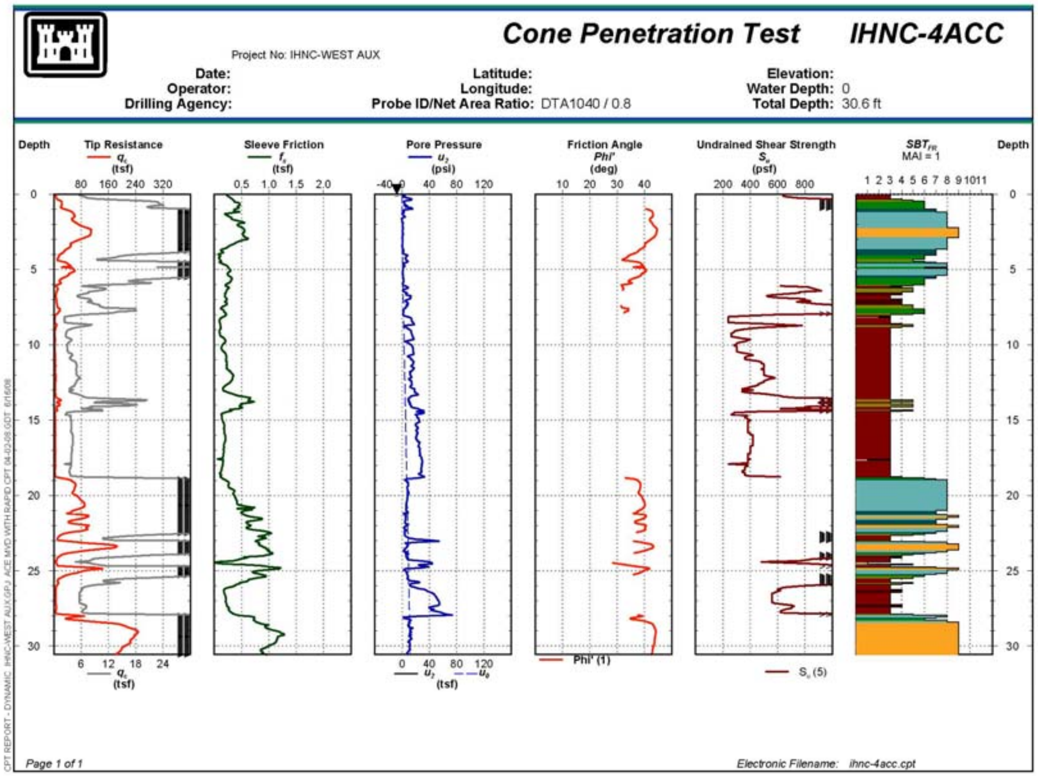
U.S. Army Corps of Engineers

Operator: Bailey
Sounding: Savannah District SCAPS
Cone Used: DTA1040

CPT Date/Time: 4/23/2007 1:54:50 PM
Location: LPV145-DHFLc
Job Number:



*Soil behavior type and SPT based on data from UBC-1983



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	PointID	Depth	Imported Depth	fs	qc	qt	u2	fs User Ur	qc User Ur	qt User Unit	u2 User Unit	u0	Total Stress	Effective Stress	FR	FR Normalized	Bq	Qt Normalized	SBT Bq Norma	SBT Fr Norma	SBT Bq	SBT Fr	Estimated Total Density
2	NDV-01-02DC-Vic	0.164	0.164041995	1	8	8	-1.36E-03	0.502	8.294	8.294	-0.001	0	0.009	0.004	6	6.06	-0	2062.6			5	3	111.4
3	NDV-01-02DC-Vic	0.328	0.32808399	1	39	39	-1.50E-02	0.791	39.229	39.226	-0.015	0	0.019	0.009	2	2.02	-0	4726.1			8	6	114.6
4	NDV-01-02DC-Vic	0.492	0.492125984	1	44	44	-2.29E-02	0.726	43.614	43.61	-0.023	0	0.028	0.013	2	1.67	-0	3394.8			8	7	117.8
5	NDV-01-02DC-Vic	0.656	0.656167979	1	40	40	-2.59E-02	0.619	39.779	39.774	-0.026	0	0.038	0.017	2	1.56	-0	2286.4			8	7	117.8
6	NDV-01-02DC-Vic	0.82	0.820209974	0	36	36	-1.13E-02	0.496	36.077	36.075	-0.011	0	0.048	0.022	1	1.38	-0	1643.5			8	7	117.8
7	NDV-01-02DC-Vic	0.984	0.984251969	0	35	35	-2.06E-02	0.478	35.405	35.401	-0.021	0	0.057	0.026	1	1.35	-0	1335.6			8	7	117.8
8	NDV-01-02DC-Vic	1.148	1.148293963	1	35	35	-2.18E-02	0.521	34.743	34.739	-0.022	0	0.067	0.031	2	1.5	-0	1118.3			7	7	117.8
9	NDV-01-02DC-Vic	1.312	1.312335958	1	35	35	-2.11E-02	0.509	34.618	34.613	-0.021	0	0.077	0.036	1	1.47	-0	971.6	7	6	7	7	117.8
10	NDV-01-02DC-Vic	1.476	1.476377953	1	34	34	6.58E-03	0.513	34.04	34.041	0.007	0	0.086	0.04	2	1.51	-0	847	7	6	7	7	117.8
11	NDV-01-02DC-Vic	1.64	1.640419948	0	33	33	-6.35E-03	0.48	33.332	33.331	-0.006	0	0.096	0.045	1	1.44	-0	744.7	7	6	7	7	117.8
12	NDV-01-02DC-Vic	1.804	1.804461942	0	34	34	-1.36E-02	0.455	33.895	33.892	-0.014	0	0.105	0.049	1	1.35	-0	696.9	7	6	7	7	117.8
13	NDV-01-02DC-Vic	1.969	1.968503937	0	31	31	-4.04E-02	0.437	30.869	30.861	-0.04	0	0.115	0.054	1	1.42	-0	572.4	7	6	7	7	117.8
14	NDV-01-02DC-Vic	2.133	2.132545932	0	32	32	-4.54E-03	0.429	31.747	31.746	-0.005	0	0.125	0.058	1	1.36	-0	542.8	7	6	7	7	117.8
15	NDV-01-02DC-Vic	2.297	2.296587927	0	31	31	-1.81E-03	0.426	31.185	31.185	-0.002	0	0.134	0.063	1	1.38	-0	494.5	7	6	7	7	117.8
16	NDV-01-02DC-Vic	2.461	2.460629921	0	32	32	4.54E-04	0.408	32.103	32.104	0	0	0.144	0.067	1	1.28	-0	474.6	7	6	7	7	117.8
17	NDV-01-02DC-Vic	2.625	2.624671916	0	31	31	-1.07E-02	0.381	30.886	30.884	-0.011	0	0.154	0.072	1	1.24	-0	427.5	7	6	7	7	117.8

	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ
1	Ic	ED	ID	KD	OCR (1)	OCR (2)	OCR (3)	Ko (1)	Ko (2)	Equivalent N60	Phi (1)	Phi (2)	Phi (3)	Su (1)	Su (2)	Su (3)	Su (4)	Su (5)	Dr (1)	Dr (2)	Dr (3)	eo	M (1)	M (2)	M (3)	St (1)	St (2)	Fines Content (1)	Fines Content (2)
2	2	42	1	258					206.3	2			64.7									1	231						
3	2	196	2	397					472.6	7			61.1									1	1174						
4	1	218	2	277					339.5	7			54.3									1	1231						
5	1	199	2	185					229.6	7			48.3									1	1047						
6	1	180	2	131					164.4	6			42.5									1	891						
7	1	177	2	106					133.6	6			39.6									1	839						
8	2	174	2	90.2					111.8	6			38.7									1	796						
9	2	173	2	78.2	320.63	-0.93	584.61		97.16	6			36.7		2.3	0.79	2.3	1.73				1	770		295	5	5		
10	2	170	2	68.4	279.52	-0.52	509.41		84.7	6			35.3		2.26	0.8	2.26	1.7				1	735		280	5	4		
11	2	167	2	59.8					74.47	6	41.7	50	33.3						72	69	96	1	699	118				31	41
12	2	169	2	54.8					68.69	6	41.5	49.7	31.5						71	67	94	1	696	123				30	39
13	2	164	2	46.9					57.24	5	40.9	49	30						66	63	99	1	609	121				32	39
14	2	159	2	43.3					54.28	6	40.6	46.7	28.8						66	63	88	1	617	126				31	38
15	2	156	2	39.6					49.45	6	40.5	48.4	27.9						64	61	86	1	593	127				32	38
16	2	161	2	37.7					47.46	6	40.5	46.2	26.6						64	61	86	1	603	131				30	37
17	2	154	2	33.9					42.75	5	40.2	47.7	25.2						61	59	83	1	564	131				31	36

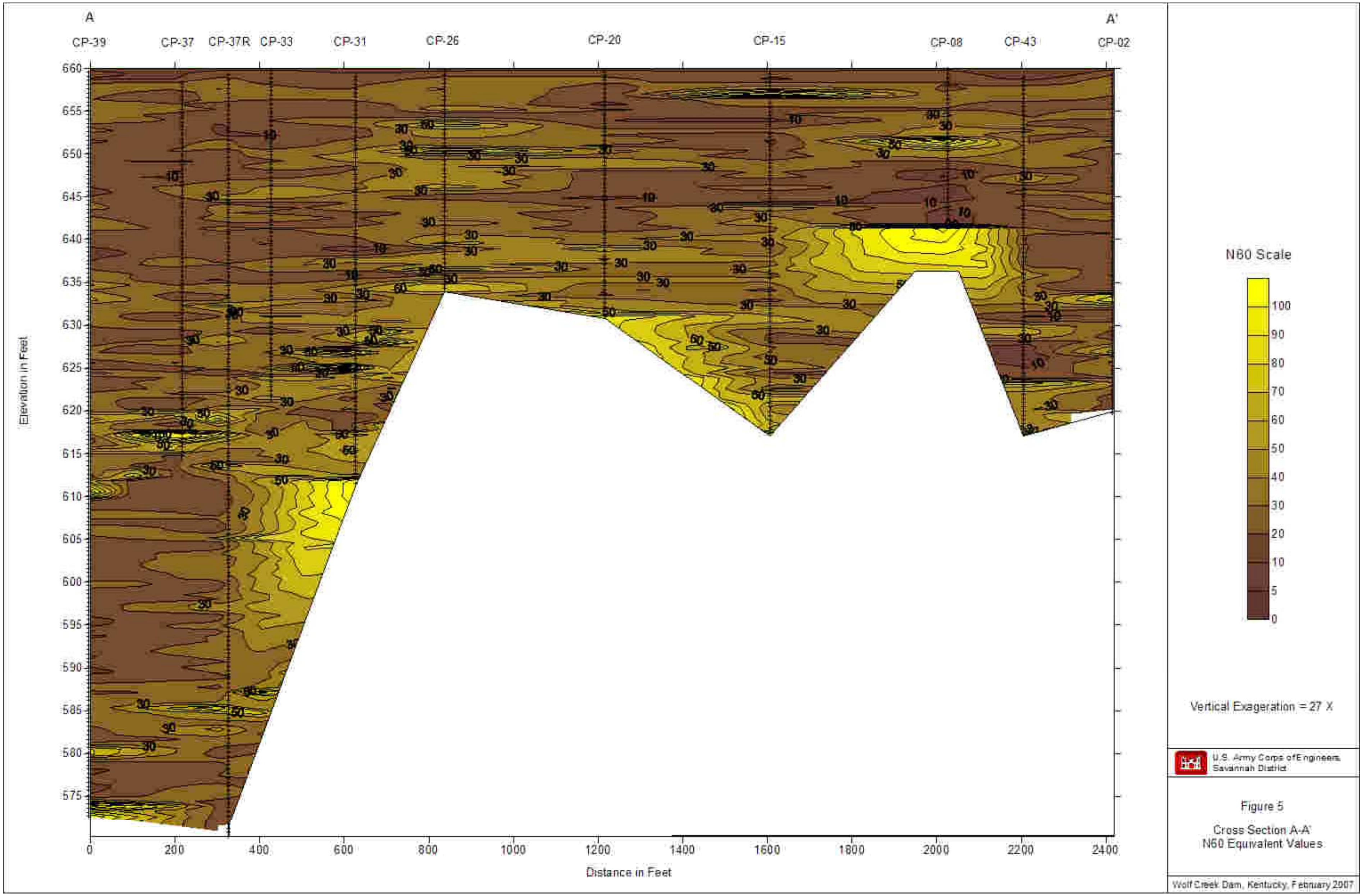
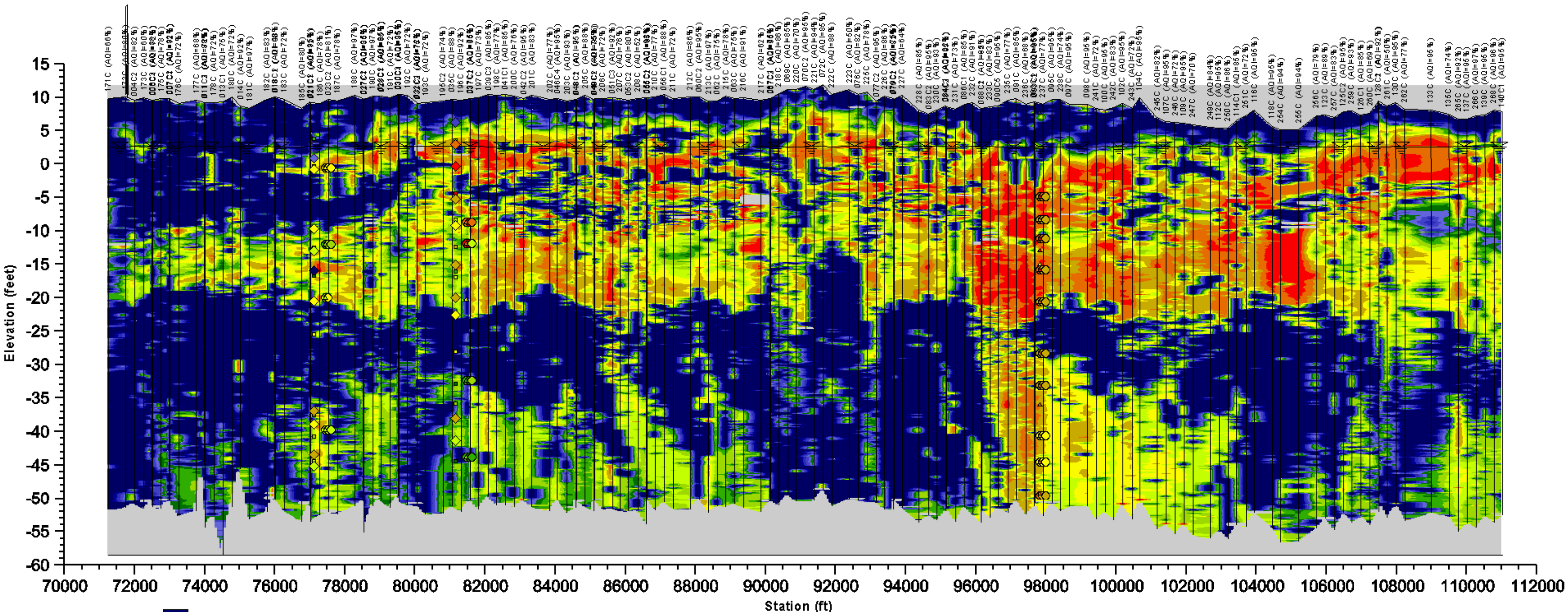


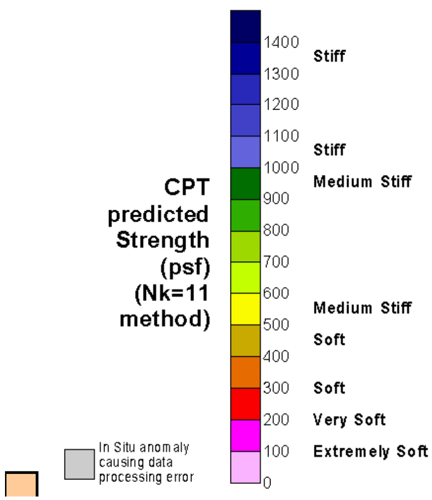
Figure 5

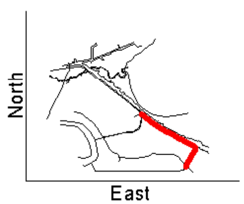
Cross Section A-A'
N60 Equivalent Values

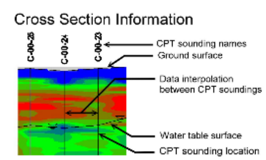
Wolf Creek Dam, Kentucky, February 2007

CPT predicted strength (using Nk = 11)







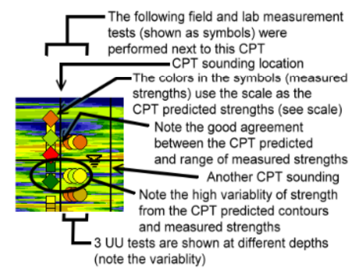


Cross Section: **146Long-LandToe-V1**

CPT cross sections were generated using soil layer tracing to connect conditions between CPT soundings. For proper evaluation of a given section, the cross sections of CPT predicted soil type, strength, and normalized strength should be available for rapid correlation. The CPT predicted techniques are based on advanced evaluation techniques developed at USACE ERDC over the last 25 years. The predicted strengths are for all soil type and strength level, ranging from undrained strengths for clays to drained strength for sands. The Academic Quality Index (AQI) is a simple but powerful tool, great data has an A grade or about 95% (great for correlations) and poor data has a D grade or about 65% (only good for tracking geologic layers).

Strength Measurement Symbols

- ○ **UU (Unconsolidated Undrained Triaxial)**
- △ **UC (Q unconfined test)**
- □ **LV (Laboratory mini vane)**
- ◇ **FV (Field vane test)**



Cross section: 146Long-LandToe-V1

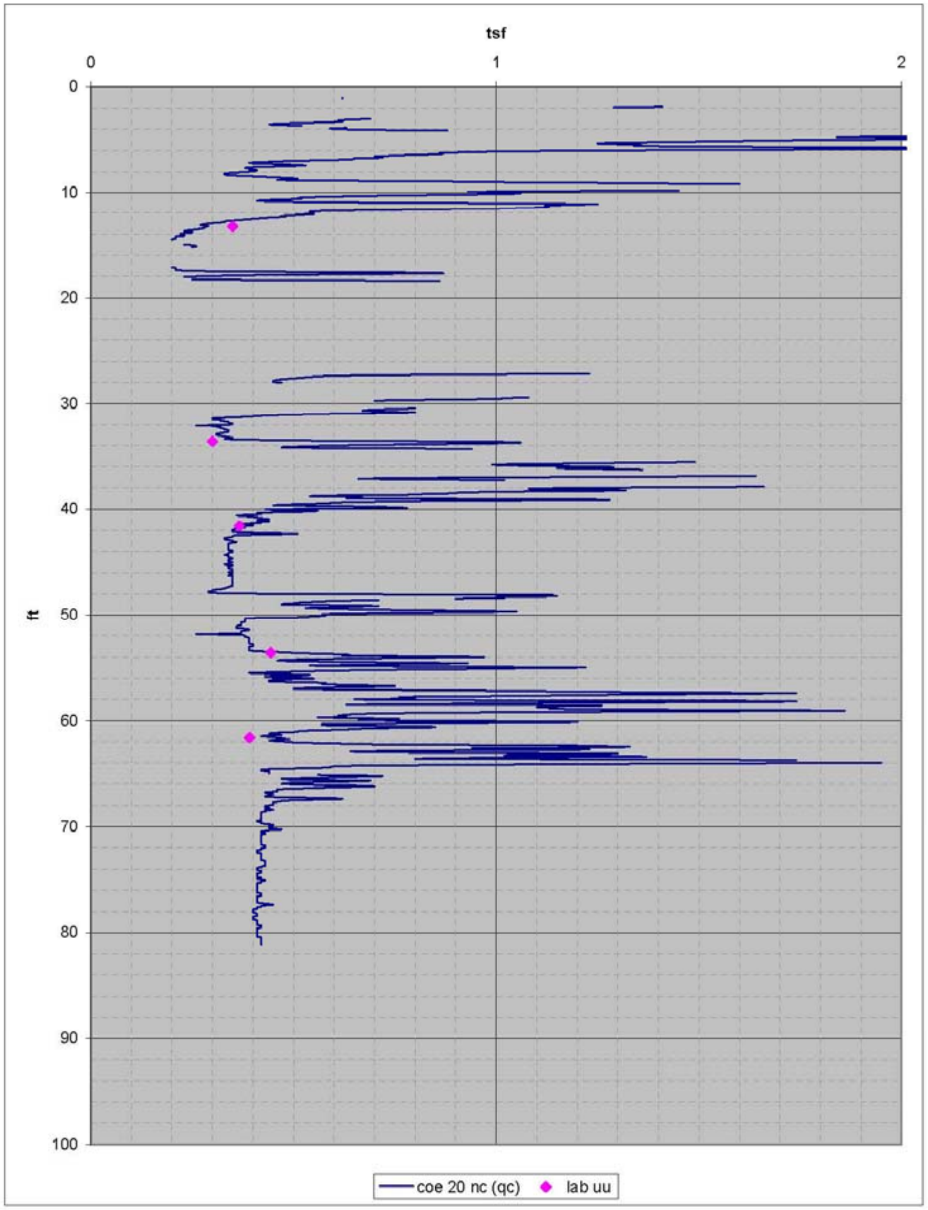
Cross section from station 712+00 to 1110+00

Richard Olsen, PhD, PE USACE-ERDC
Geo-Omaha Conference - Feb 15, 2008

Estimated parameters from standard CPTu

- Undrained shear strength, S_u
- Drained friction angle, phi
- Stress History, OCR
- Equivalent N_{60}
- Coefficient of lateral earth stress, K_o
- Total density, relative density and void ratio, ρ , D_R, e_o
- Constrained modulus, M
- Sensitivity, S_t
- Fines Content
- Additional parameters

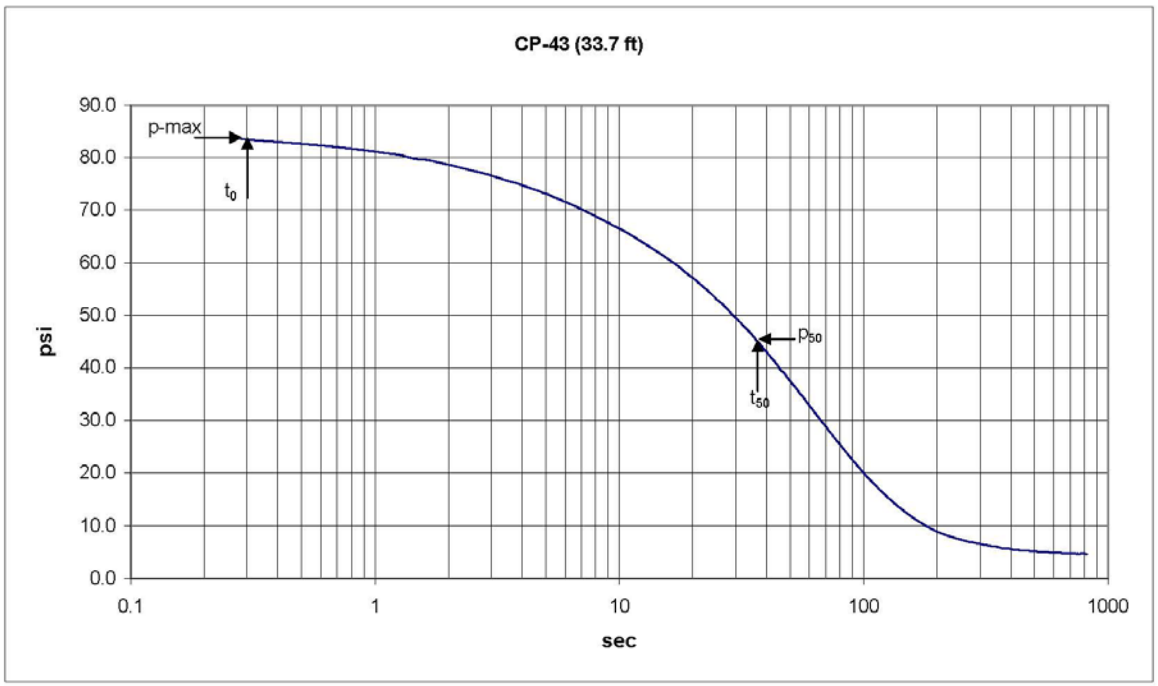
Undrained shear strength example



- Theoretical solutions exist to predict a number of design parameters from CPT data including S_u.
- Another common method is to use site specific laboratory data to “calibrate” CPT results.
- Limited number of borings done under tight QA/QC.
- Laboratory results used to derive factors that are applied to CPT data to produce a best fit with lab data.
- Factors are then applied to larger number of CPT soundings.

Pore pressure dissipation

Wolf Creek Dam
Dissipation Test, February 2007



	p-max	p-min	delta	p_{50}	t_0	t_{50}
psi	83.433	4.699	78.734	44.066		
sec	0.283	740.064	739.781	39.066	0.283	38.783

Estimation of horizontal hydraulic conductivity: K_h= 1.03E-05 cm/sec

Depth of hydrostatic head from ground surface: -22.8 ft

- Pore pressure measured during push is induced by probe displacing saturated soil.
- When push is paused, rate of dissipation is linked to the coefficient of consolidation (c_{vh}), which is linked to hydraulic conductivity (k).

$$c_{vh} = \frac{T_{50} * \cdot a_c^{\ 2} \cdot \sqrt{I_R}}{t_{50}}$$

$$c_{vh} = \frac{k \cdot D'}{\gamma_w}$$

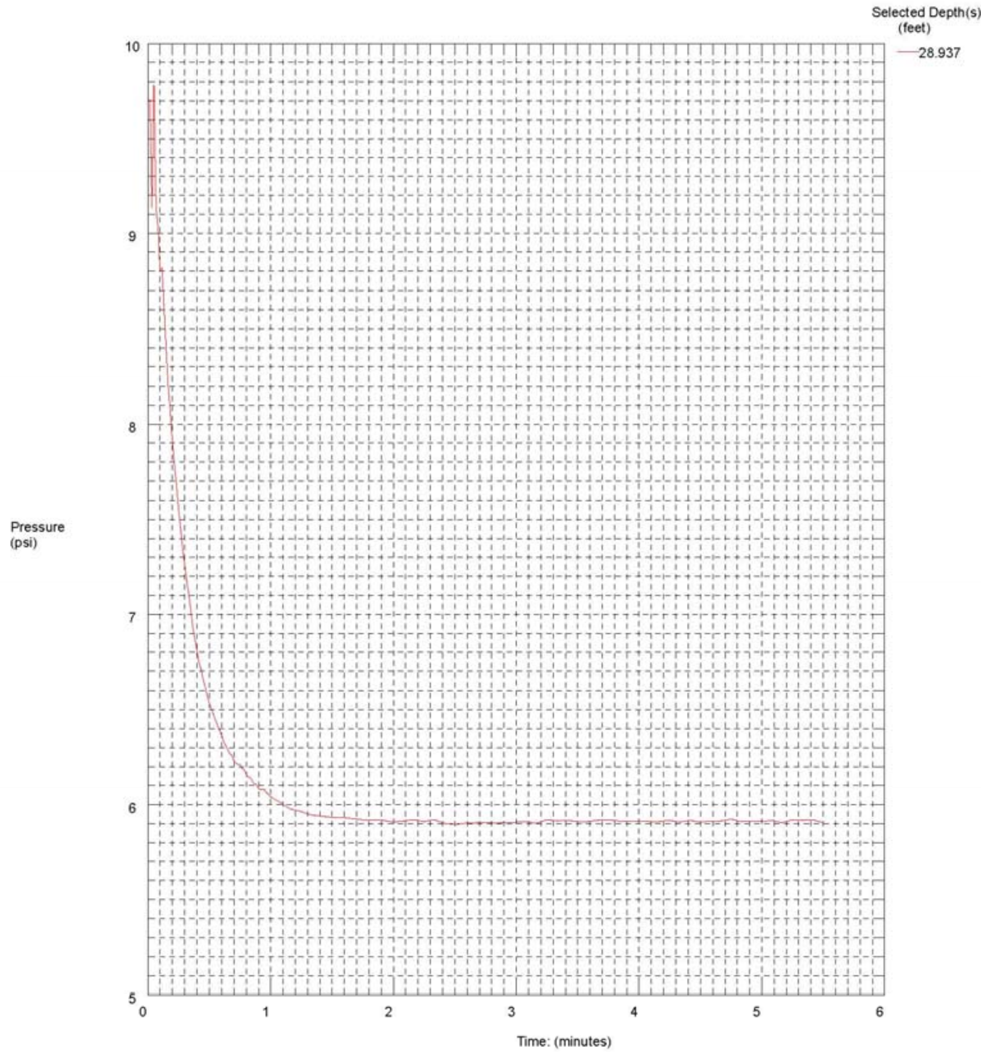
Where: D' = constrained modulus, a = cone radius, I_R = rigidity index, T_{50} = time factor based on cone radius

Source: NCHRP Synthesis 368

U.S. Army Corps of Engineers

Operator MARKOV
Sounding: NOV06-117C
Cone Used: DDG1069

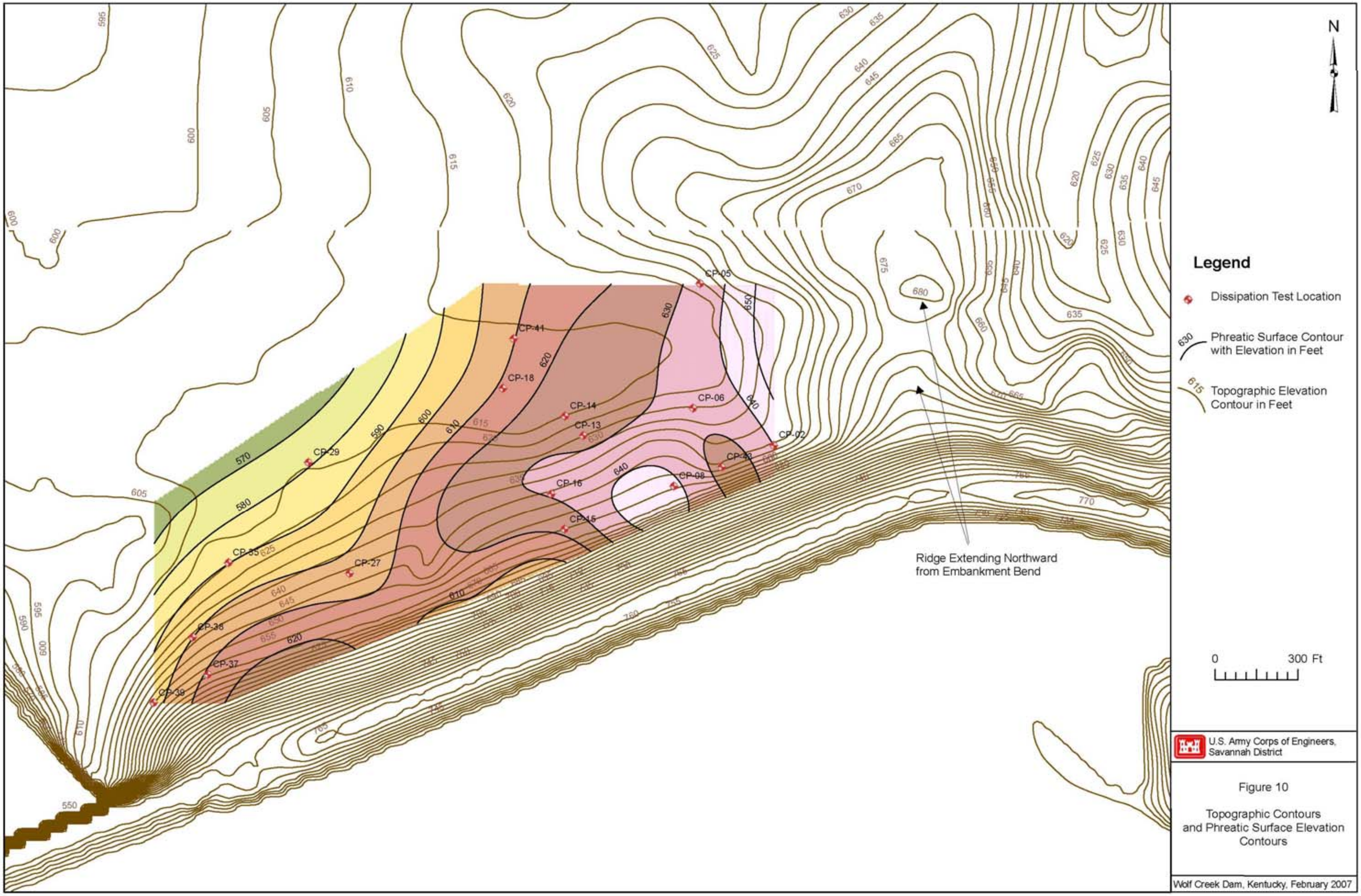
CPT Date/Time: 7/29/2008 12:26:17 AM
Location: N29.45215 W89.6693
Job Number: NOV06



Maximum Pressure = 9.783 psi
Hydrostatic Pressure = 5.923 psi

Figure 9

Elevation Contours of Phreatic Surface



N
Legend
Dissipation Test Location
Phreatic Surface Contour with Elevation in Feet
Topographic Elevation Contour in Feet
0 300 Ft
Ridge Extending Northward from Embankment Bend
U.S. Army Corps of Engineers, Savannah District
Figure 10
Topographic Contours and Phreatic Surface Elevation Contours
Wolf Creek Dam, Kentucky, February 2007

N

Legend

- Dissipation Test Location
- **> 20 Ft. Below G.S.**
- **10-20 Ft. Below G.S.**
- **0-10 Ft. Below G.S.**
- **0-10 Ft. Above G.S.**
- **> 10 Ft. Above G.S.**

Notes:
G.S. = ground surface.

Interpolation is only valid within test grid.

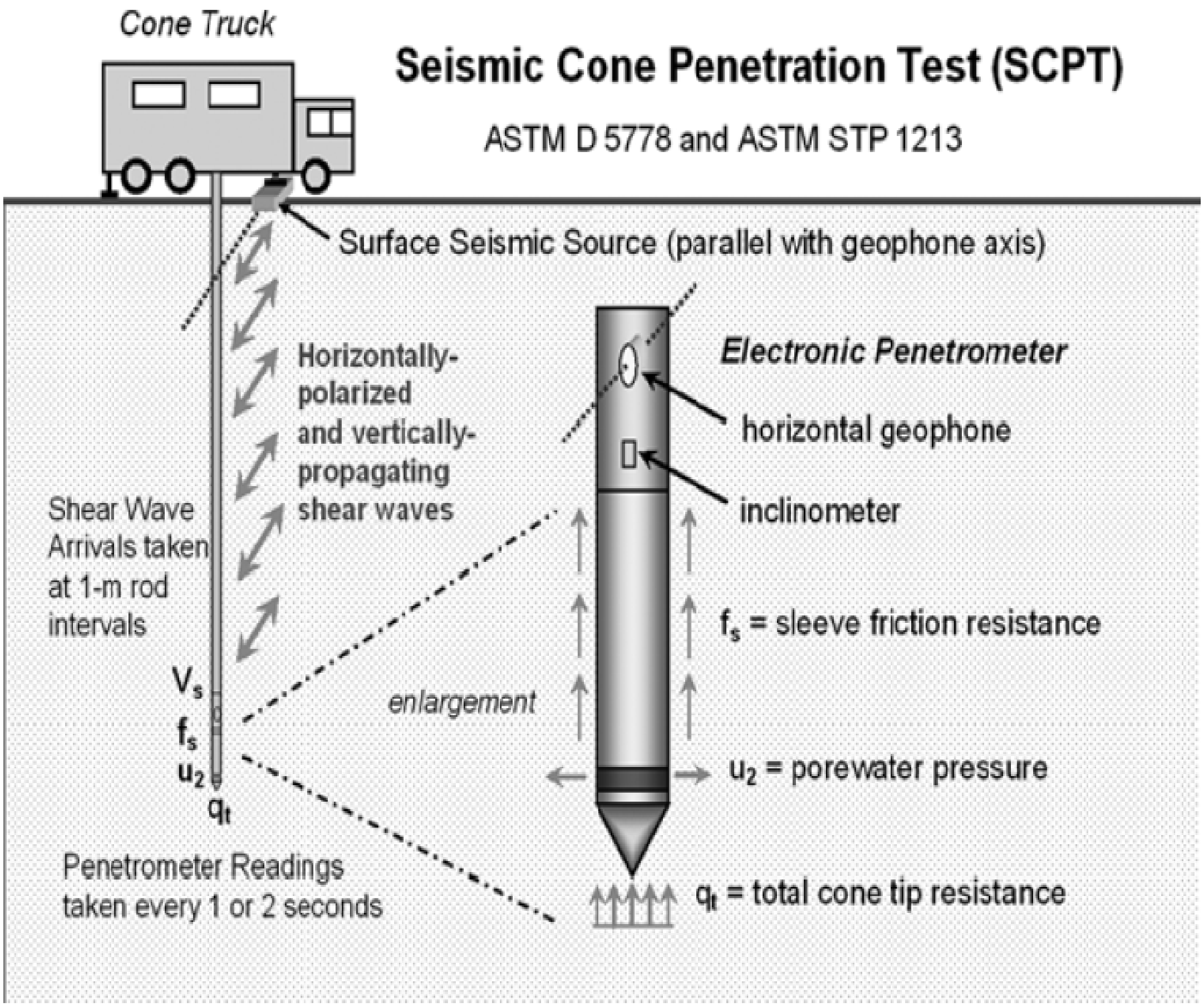
0 300 Ft

U.S. Army Corps of Engineers, Savannah District

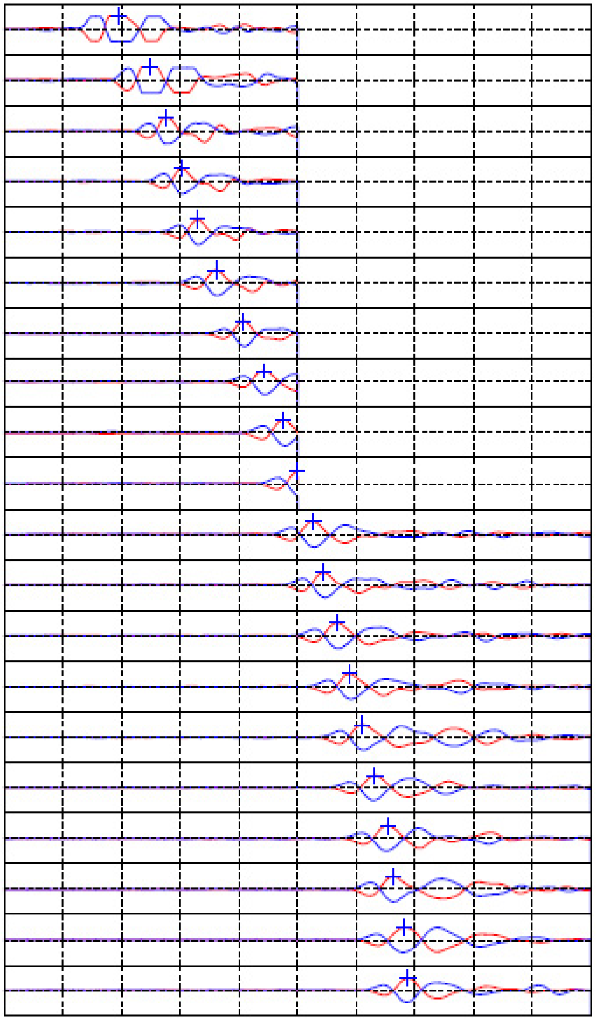
Figure 11

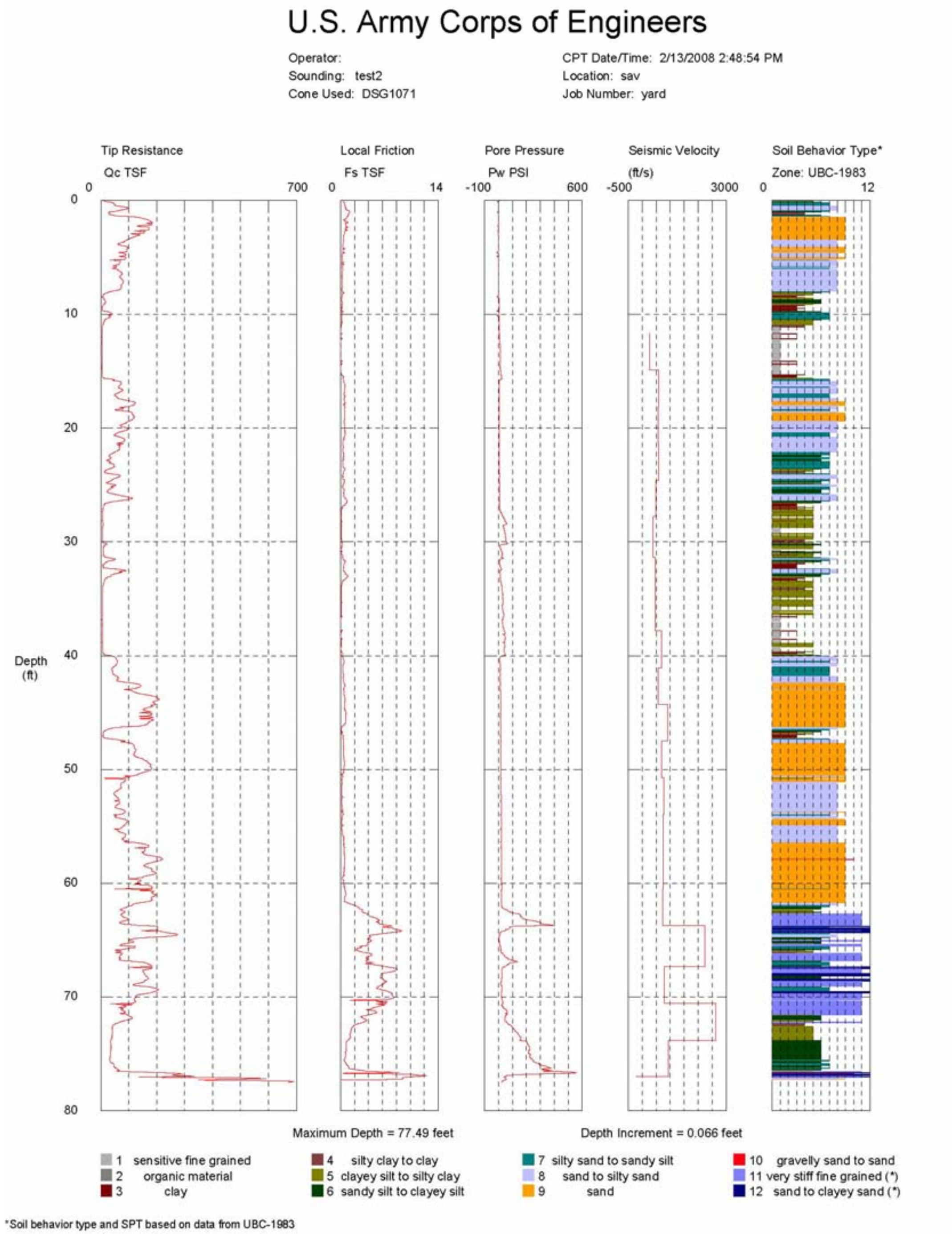
Hydraulic Head in Relation to Ground Surface

Wolf Creek Dam, Kentucky, February 2007



Source: NCHRP Synthesis 368




U.S. Army Corps of Engineers
Operator:
Sounding: test2
Cone Used: DSG1071
CPT Date/Time: 2/13/2008 2:48:54 PM
Location: sav
Job Number: yard
Tip Resistance
Qc TSF
Local Friction
Fs TSF
Pore Pressure
Pw PSI
Seismic Velocity
(ft/s)
Soil Behavior Type*
Zone: UBC-1983
Depth
(ft)
Maximum Depth = 77.49 feet
Depth Increment = 0.066 feet
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)
*Soil behavior type and SPT based on data from UBC-1983