

بسمه تعالی

دانشگاه شهید باهنر کرمان
دانشکده فنی و مهندسی
بخش مهندسی معدن

بررسی ساختگاهی
ترم اول ۱۳۹۷
(۸)

سعید کریمی نسب

Site Investigation Course-1397
Kariminasab

Soil Samples

Soil Samples

- Soil samples obtained for engineering testing and analysis, in general, are of two main categories:
- Disturbed (but representative)
- Undisturbed

Disturbed Samples

- Disturbed samples are those obtained using equipment that destroy the macro structure of the soil but do not alter its mineralogical composition.

Disturbed Samples

- To determine general lithology of soil deposits, for identification of soil components and general classification purposes, for determining grain size, Atterberg limits, and compaction characteristics of soils.

Disturbed Samples

- Disturbed samples can be obtained with a number of different methods as summarized in Table 3-4.

Sampler	*Disturbed / Undisturbed*	*Appropriate Soil Types*	*Method of Penetration*	*% Use in Practice*
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	6
Continuous Push	Partially Undisturbed	Sands, silts, & clays	Hydraulic push with plastic lining	4
Piston	Undisturbed	Silts and clays	Hydraulic Push	1
Pitcher	Undisturbed	Stiff to hard clay, silt, sand, partially weather rock, and frozen or resin impregnated granular soil	Rotation and hydraulic pressure	<1
Denison	Undisturbed	Stiff to hard clay, silt, sand and partially weather rock	Rotation and hydraulic pressure	<1
Modified California	Disturbed	Sands, silts, clays, and gravels	Hammer driven (large split spoon)	<1
Continuous Auger	Disturbed	Cohesive soils	Drilling w/ Hollow Stem Augers	<1
Bulk	Disturbed	Gravels, Sands, Silts, Clays	Hand tools, bucket augering	<1
Block	Undisturbed	Cohesive soils and frozen or resin impregnated granular soil	Hand tools	<1

Undisturbed Samples

- Undisturbed samples are obtained in clay soil strata for use in laboratory testing to determine the engineering properties of those soils.
- Undisturbed samples of granular soils can be obtained, but often specialized procedures are required such as freezing or resin impregnation and block or core type sampling.

Sampler	*Disturbed / Undisturbed*	*Appropriate Soil Types*	*Method of Penetration*	*% Use in Practice*
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Bulk	Disturbed	Gravels, Sands, Silts, Clays	Hand tools, bucket augering	<1
Block	Undisturbed	Cohesive soils and frozen or resin impregnated granular soil	Hand tools	<1

Undisturbed Samples

- It should be noted that the term "undisturbed" soil sample refers to the relative degree of disturbance to the soil's in-situ properties.
- Undisturbed samples are obtained with specialized equipment designed to minimize the disturbance to the in-situ structure and moisture content of the soils.

Split Barrel Sampler

- The split-barrel (or split spoon) sampler is used to obtain disturbed samples in all types of soils.

Split Barrel Sampler

- The split spoon sampler is typically used in conjunction with the *Standard Penetration Test* (SPT), as specified in AASHTO T206 and ASTM D1586.

Split Barrel Sampler

- In general, the split-barrel samplers are available in standard lengths of 457 mm and 610 mm with inside diameters ranging from 38.1 mm to 114.3 mm in 12.7 mm increments

Split Barrel Sampler

- The 38.1 mm (1.5 in) inside diameter sampler is popular because correlations have been developed between the number of blows required for penetration and a few select soil properties.

Split Barrel Sampler

- The larger diameter samplers (inside diameter larger than 51 mm (2 in) are sometimes used when gravel particles are present or when more material is needed for classification tests.

Split-Barrel Samplers:
Lengths of 457 mm and 610 mm



Split-Barrel Samplers:
Inside diameters from 38.1 mm to 89 mm





STANDARD PENETRATION TEST

- The SPT involves the driving of a hollow thick-walled tube into the ground and measuring the number of blows to advance the split-barrel sampler a vertical distance of 300 mm (1 foot).

STANDARD PENETRATION TEST

- A drop weight system is used for the pounding where a 63.5-kg (140-lb) hammer repeatedly falls from 0.76 m (30 inches) to achieve three successive increments of 150-mm (6-inches) each.

STANDARD PENETRATION TEST

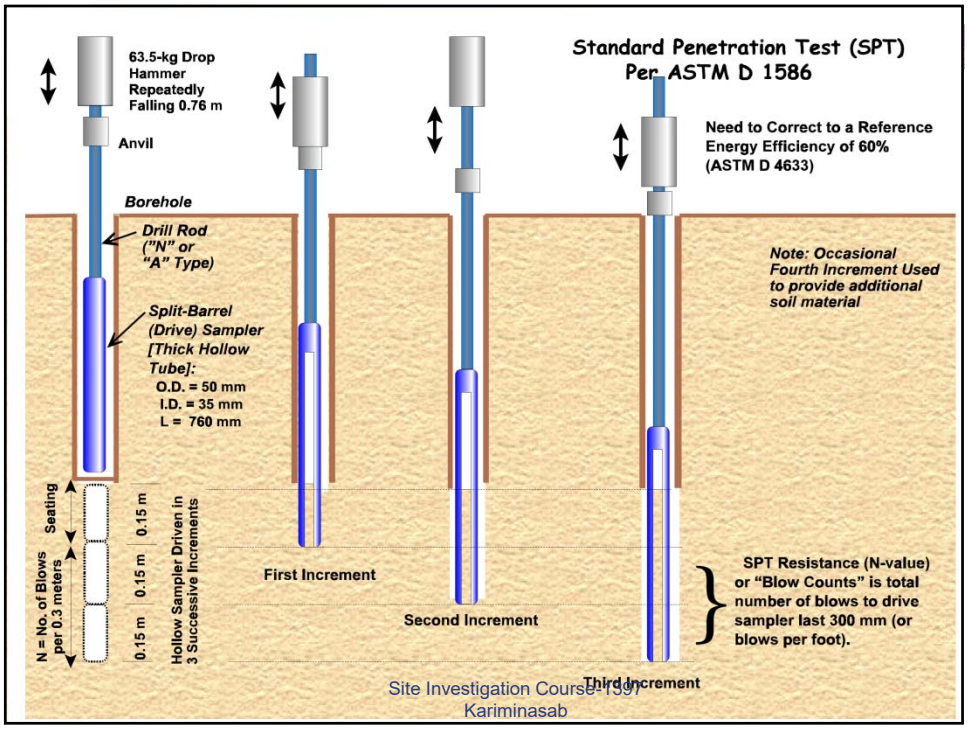
- The first increment is recorded as a “seating”, while the number of blows to advance the second and third increments are summed to give the N-value ("blow count") or SPT-resistance (reported in blows/0.3 m or blows per foot).

STANDARD PENETRATION TEST

- If the sampler cannot be driven 450 mm, the number of blows per each 150-mm increment and per each partial increment is recorded on the boring log.

STANDARD PENETRATION TEST

- For partial increments, the depth of penetration is recorded in addition to the number of blows.



STANDARD PENETRATION TEST

- The SPT is conducted at the bottom of a soil boring that has been prepared using either flight augers or rotary wash drilling methods.

STANDARD PENETRATION TEST

- At regular depth intervals, the drilling process is interrupted to perform the SPT.

STANDARD PENETRATION TEST

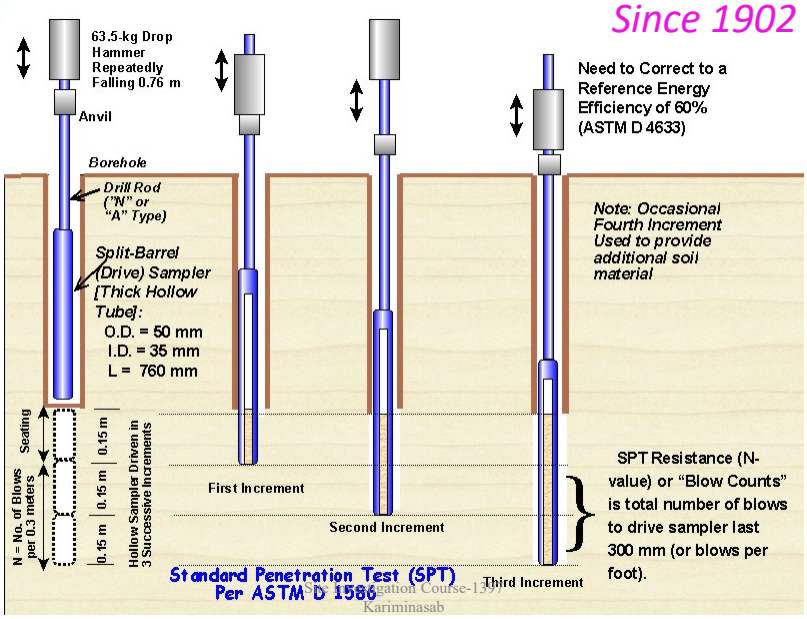
- Generally, tests are taken every 0.76 m (2.5 feet) at depths shallower than 3 meters (10 feet) and at intervals of 1.5 m (5.0 feet) thereafter.
- The head of water in the borehole must be maintained at or above the ambient groundwater level to avoid inflow of water and borehole instability.

Standard Penetration Test (SPT)

Prepared by Paul W. Mayne
Georgia Institute of Technology
2016

Standard Penetration Test (SPT)

Since 1902



Split-Spoon or Split-Barrel Sampler

jar samples

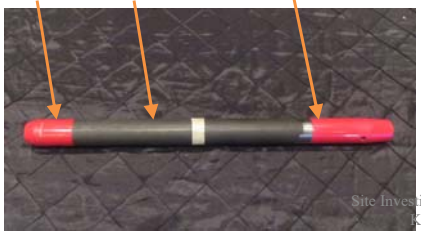
thin-walled tube sampler



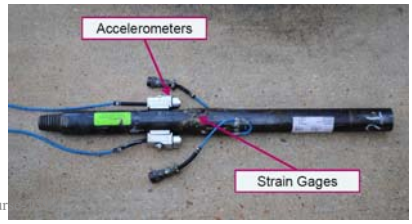
split-barrel sampler



shoe split-barrel head (connects to rods)



instrumented split-barrel sampler for taking energy measurements



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Split-Spoon or Split-Barrel Sampler



box of split-barrel samples in jars with split-spoon (DeJong 2002)

split-barrel sample 2 from Kurtulus (2006 Univ. Texas-Austin)



split-barrel sample 3 from Kurtulus (2006 Univ. Texas-Austin)



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Disadvantage of SPT (Idriss & Boulanger 2008)

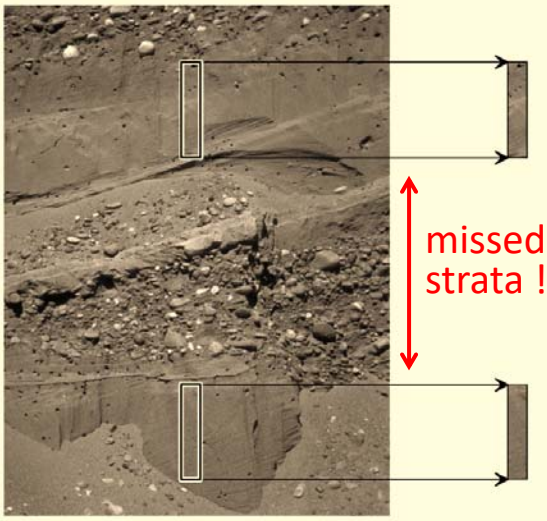
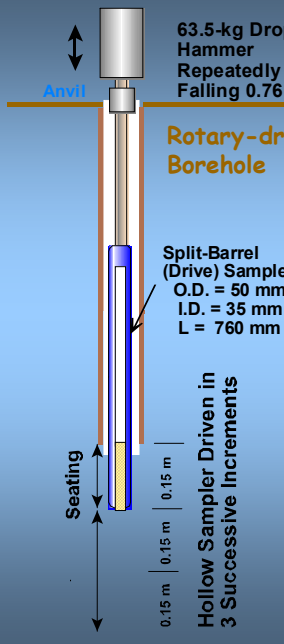


Figure 57. An excavation face showing the interlayering of sand, gravelly sand, and sandy gravel in an alluvial deposit and the portion of the deposit that would be observed via SPT samples at 1.5-m intervals.

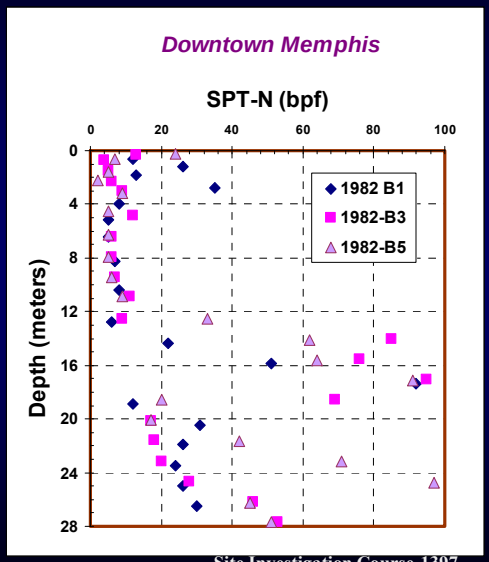
Standard Penetration Test





Standard Penetration Test (SPT)
Procedures: ASTM D 1586
N = measured Number of Blows to drive sampler 300 mm into soil.

Representative SPT Profile





Standard Penetration Test

Advantages

- Obtain Sample + Number
- Simple & rugged device at low cost
- Suitable in many soil types
- Can perform in weak rocks
- Available (worldwide)



Standard Penetration Test

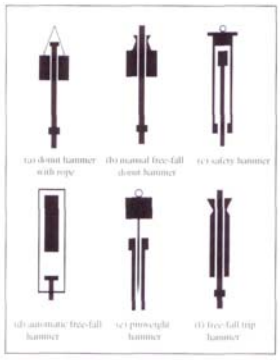
Disadvantages

- Obtain Sample + Number
- Energy inefficiency problems
- Discontinuous - only taken every 5 feet (1.5 m)
- Disturbed sample (index tests only)
- Crude number for analysis
- Not applicable in soft clays and silts
- High variability and uncertainty

SPT Hammer Types

Split-spoon





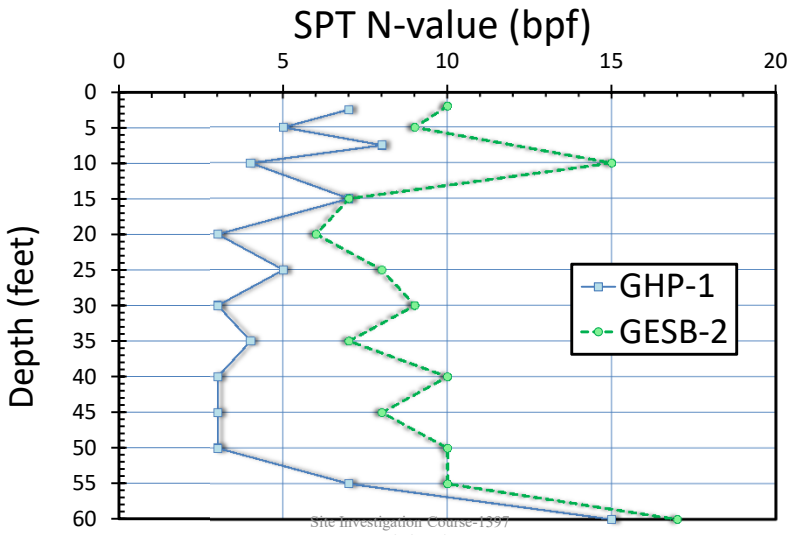


- Pinweight
- Donut*
- Donut**
- Safety*
- Safety**
- Auto

NOTES
*cathead-rope
**trip (free-fall)

2015 DeKalb County, Georgia

Results from nearby borings by two drilling firms



SPT Hammers





PINWEIGHT



SAFETY







DONUT



AUTO



Calibration of SPT Hammer & System

Modified after Kulhawy and Mayne (1990)

Hammer Type	Operation Method	Typical Range of Energy Ratios
Pinweight	Manual	30 - 40
Donut	Manual	40 - 55
Safety	Manual	50 - 75
Automatic	Auto	45 - 95

Corrections to SPT N-value

- A calibration of energy efficiency for a specific drill rig & operator is recommended by ASTM D-4633 using instrumented strain gages and accelerometer measurements in order to better standardize the energy levels.

Corrections to SPT N-value

- Standards of practice varies from about 35% to 85% with cathead systems using donut or safety hammers, but averages about 60%.

Corrections to SPT N-value

- The newer automatic trip-hammers can deliver between 80 to 100% efficiency, but specifically depends on the type of commercial system.

Corrections to SPT N-value

- If the efficiency is measured (Ef), then the energy-corrected N-value (adjusted to 60% efficiency) is designated N_{60} and given by:

$$N_{60} = (Ef/60)\, N_{meas}$$

Corrections to SPT N-value

- The measured N-values should be corrected to N_{60} for all soils, if possible.

- The relative magnitudes of corrections for energy efficiency, sampler lining, rod lengths, and borehole diameter are given by Skempton (1986) and Kulhawy & Mayne (1990), but only as a general guide.

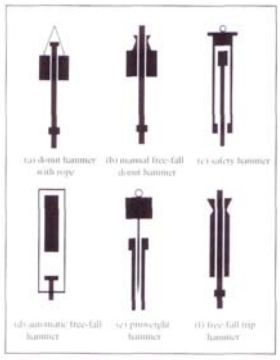
Corrections to SPT N-value

- It is mandatory to measure Ef to get the proper correction to N_{60}.

SPT Hammer Types

Split-spoon







- Pinweight
- Donut*
- Donut**
- Safety*
- Safety**
- Auto

NOTES
*cathead-rope
**trip (free-fall)

SPT Hammers





PINWEIGHT



SAFETY







DONUT



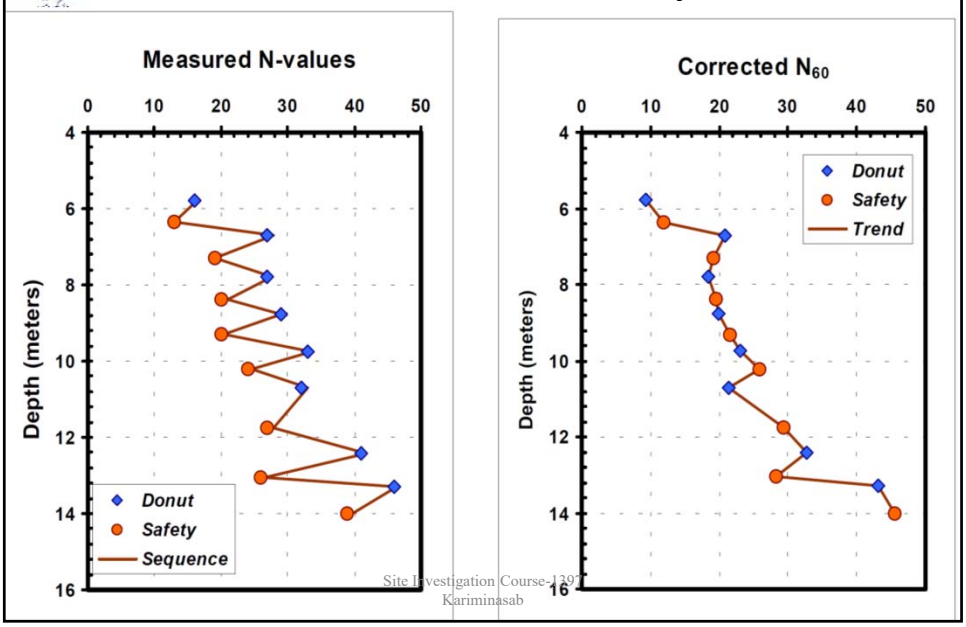
AUTO



Corrections to SPT N-value

- Exemplifies the need for correcting N-values to a reference energy level where the successive SPTs were conducted by alternating use of donut and safety hammers in the same borehole.

SPT-N values from (a) Uncorrected Data and (b) Corrected to 60% Efficiency



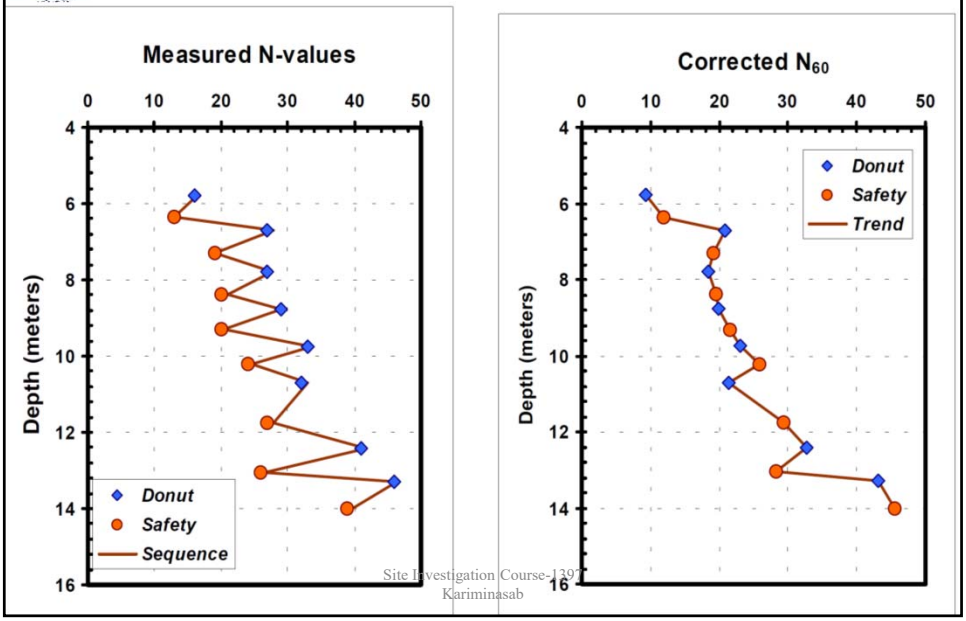
Corrections to SPT N-value

- The energy ratios were measured for each test and gave **34 < ER < 56** for the donut hammer (average = 45%) and ranged **55 < ER < 69** for the safety hammer (average = 60%) at this site.

Corrections to SPT N-value

- The individual trends for the measured N-values from donut and safety hammers are quite apparent in Figure "a", whereas a consistent profile is obtained in Figure "b" once the data have been corrected to ER = 60%.

SPT-N values from (a) Uncorrected Data and (b) Corrected to 60% Efficiency



Corrections to SPT N-value

- $N_{measured}$ = raw SPT Resistance reported in blows per foot (bpf) per ASTM D 1586. Note: in SI units, N is in units of blows/0.3 m
- $N_{60} = (ER/60)\, N_{measured} = C_E \cdot N_{meas}$ = Energy-Corrected N Value where ER = energy ratio or rated efficiency (ASTM D 4633). Note: 30% < ER < 100% with average ER = 60% in the U.S. circa 1985
- $N_{60} \approx C_E \cdot C_B \cdot C_S \cdot C_R \cdot N_{meas}$ = Fully corrected N value

Rod length correction
Split spoon liner correction
Borehole diameter correction
Energy correction

Corrections to SPT N-value

- In some correlative relationships, the energy-corrected N_{60} value is further normalized for the effects of overburden stress, designated $(N_1)_{60}$.
- The $(N_1)_{60}$ involves evaluations in clean sands for interpretations of relative density, friction angle, and liquefaction potential.

Corrections to SPT N-value

- For Clean Sands: Stress-normalization of SPT-N value: $(N_1)_{60} = C_N N_{60}$ = Energy-corrected N-value normalized to an effective overburden stress of one atmosphere.

- Note: this is often called an "overburden correction".

Corrections to SPT N-value

- Classically: $(N_1)_{60} = (N_{60})/(\sigma_{vo}')^{0.5}$ with stress given in atmospheres.

- Alternatively: $C_N = (\sigma_{atm}/\sigma_{vo}')^{0.5}$ where σ_{atm} = 1 atm ≈ 1 bar = 100 kPa ≈ 1 tsf).

- Recent approach by Boulanger & Idriss (2003, 2008, 2014), the exponent m = 0.5 is a variable that is dependent on relative density of the sand.

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Calibration of SPT Hammer & System







ASTM D 4633 - Energy Measurements
SPT Analyzer by Pile Dynamics Inc.

Calibration of SPT Hammer & System

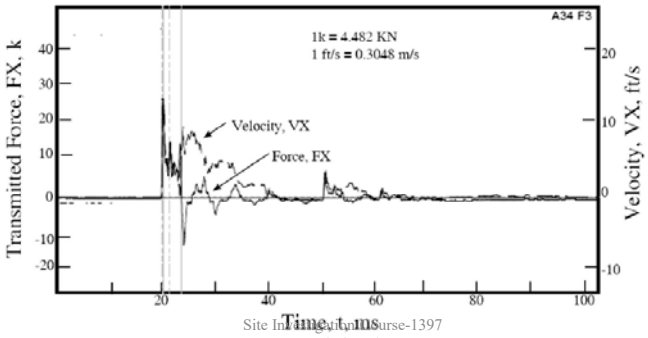
ASTM D 4633 - Energy Measurements

KE = measured kinetic energy

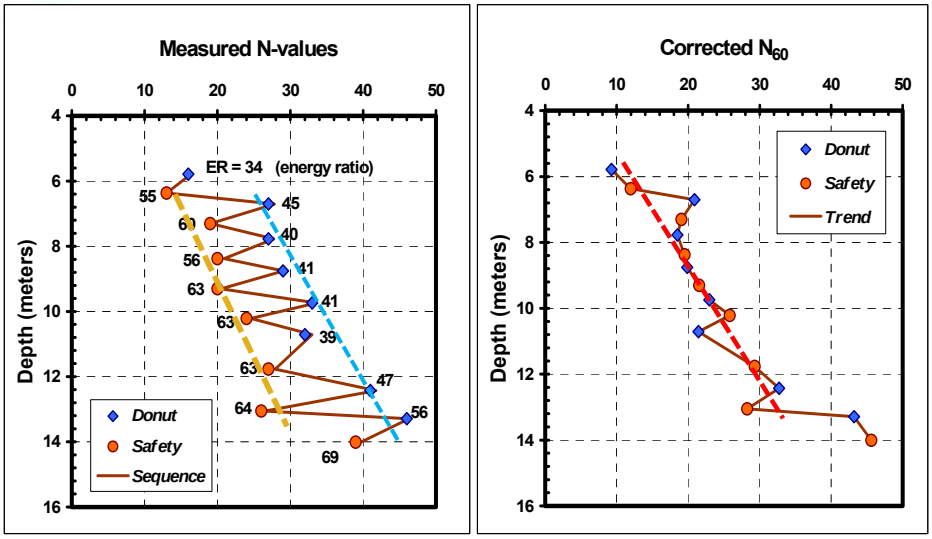
PE = potential energy = 140 lbs · 30" = 4200 in-lbs

ER = KE/PE = energy rating (%)

C_E = correction factor = ER/60



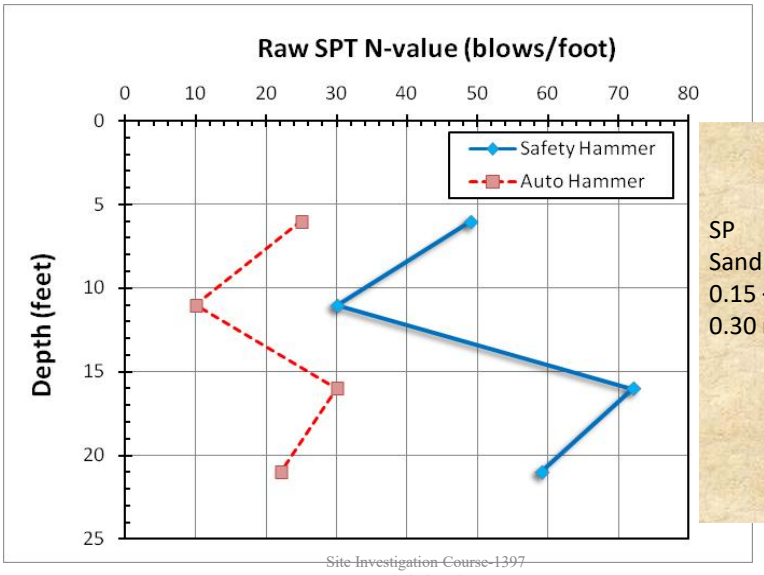
Standard Penetration Test (SPT) in Uniform Sand



Data modified from from Robertson, et al. (JGE 1983)

Northwestern University

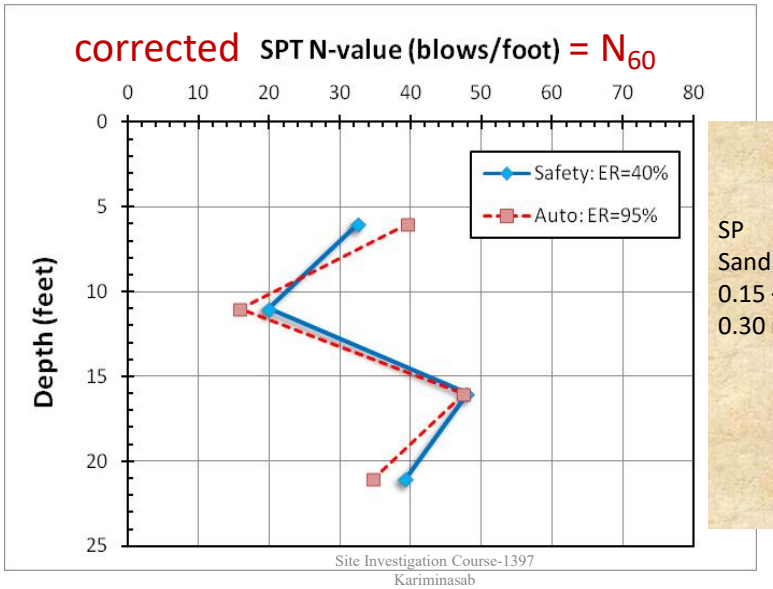
National Geotechnical Experimentation Site (Finno 2000)



SP
Sand Layer
$0.15 < D_{50} < 0.30$ mm

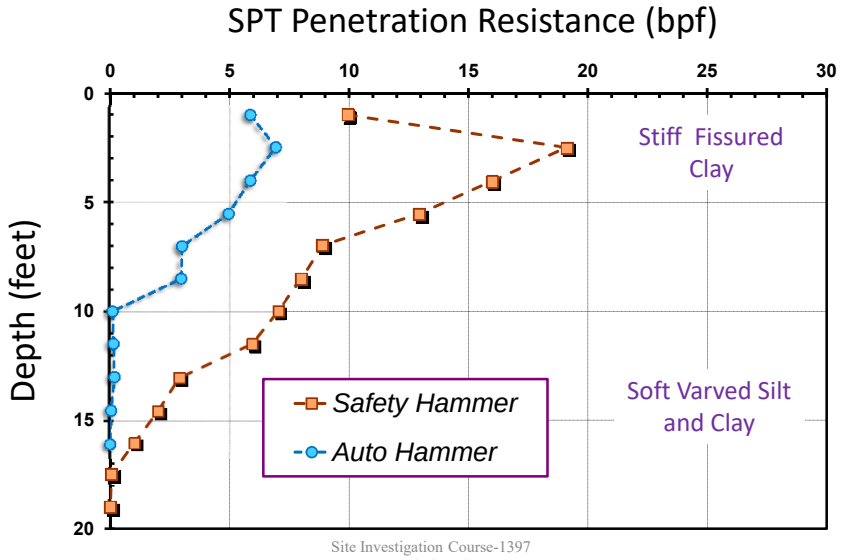
Northwestern University

National Geotechnical Experimentation Site (Finno 2000)



SP
Sand Layer
$0.15 < D_{50} < 0.30$ mm

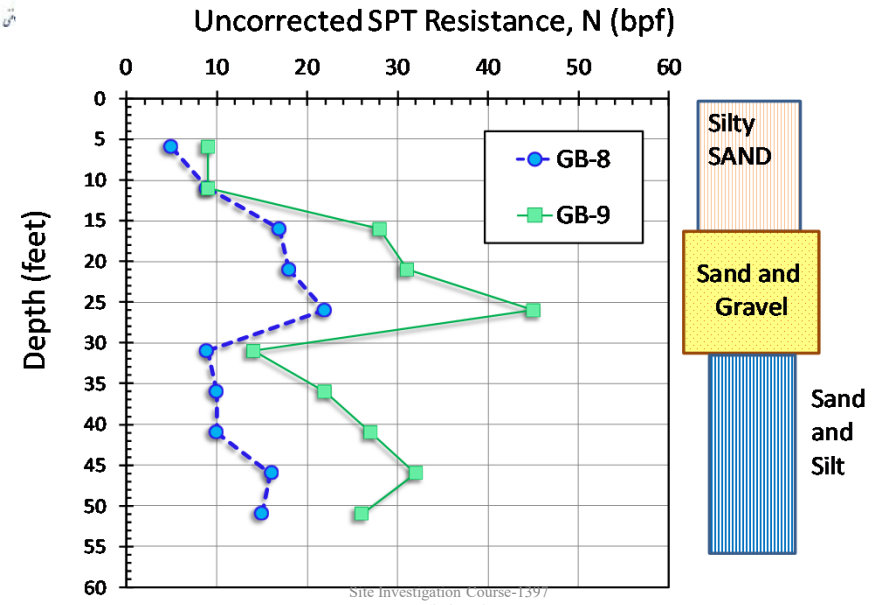
NGES at Univ. Mass - Amherst



VTRANS Study (2010) on SPT hammer systems

- 5 different drill rigs: CME45 skid, CME 55, CME 45c track, CME 75, Mobile Simco truck
- 2 types of rods: AWJ and NWJ
- 2 types of boreholes: hollow stem augers, flush casing
- 3 types of hammers: Auto, Safety, Downhole
- All 140-lb hammers falling 30 inches to drive split spoon

VTRANS Study (2010) on SPT hammer systems



VTRANS Study (2010) on SPT hammer systems

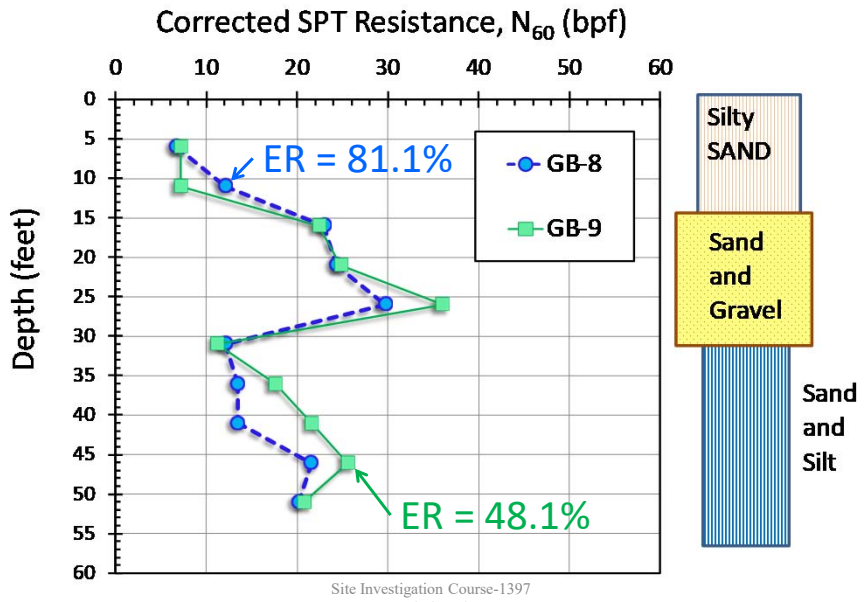
CME 45c Track
for Boring GB-8
ER = 81.1%

Simco Truck Rig
for Boring GB-9
ER = 48.1%

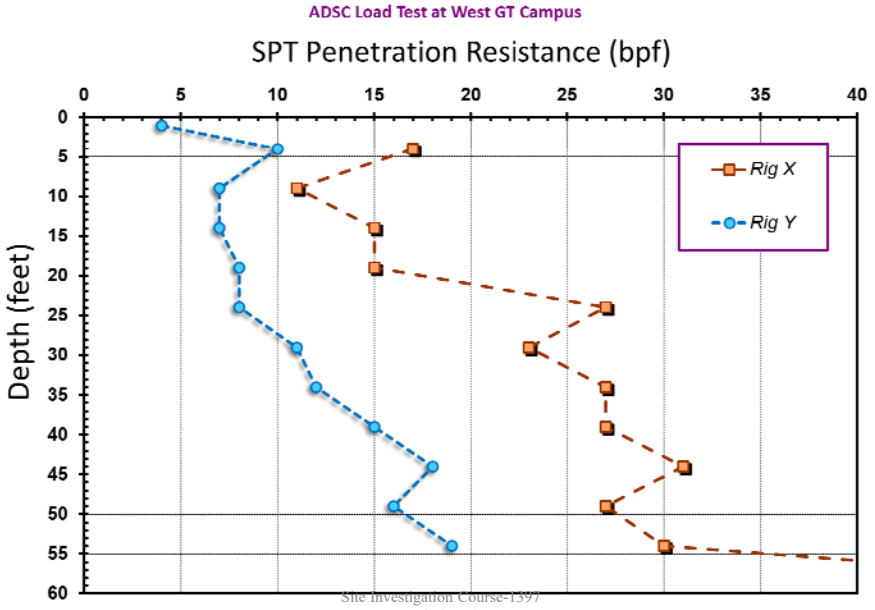




VTRANS Study (2010) on SPT hammer systems

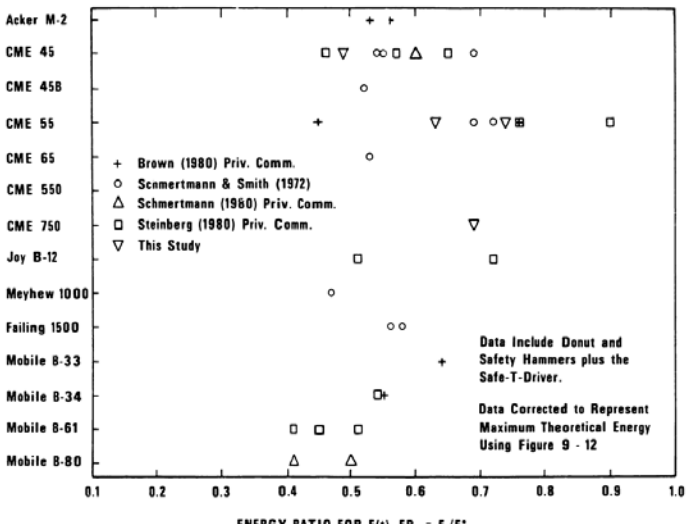


ADSC-ASCE-FHWA Load Tests at GT



Calibration of SPT Energy Efficiencies

Kovacs, Salamone, & Yokel (NIST 1981)



Donut and Safety Hammers

Calibration of SPT Energy Efficiencies

CALTRANS (March 2015) - partial list: www.dot.ca.gov

RANGE: $0.73 \leq C_E \leq 1.65$ where $C_E = ER/60$

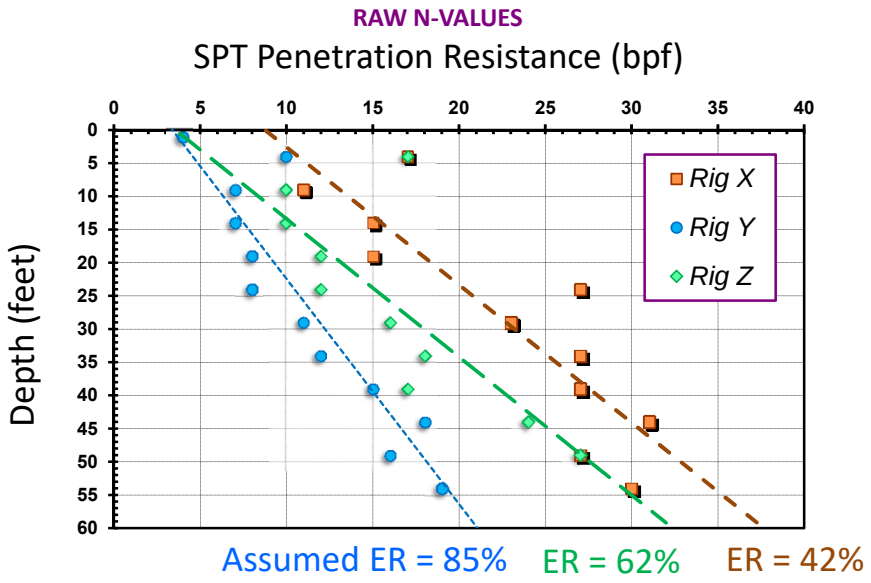
Drill Rig	Equipment C No.	Hammer Efficiency (%)	N-value Adjustment for Hammer	Source
Acker 4x4 Truck	1974	83	1.38	4/30/2009 HET Report
	1974	80	1.33	5/6/2011 HET Report
	1974	69	1.15	4/26/2013 HET Report
	1974	67	1.12	5/23/14 HET Report
Acker 4x4 Truck	0398	74	1.23	3/20/2008 HET Report
	0398	77	1.28	8/10/2010 HET Report
	0398	71	1.18	4/26/2013 HET Report
Acker 4x4 Truck	3711	68	1.13	6/25/2008 HET Report
	3711	68	1.13	5/6//2011 HET Report
	3711	52	0.87	2/1/2012 HET Report
	3711	58	0.96	4/26/2013 HET Report
	3711	60	1.00	5/10/2015 HET Report
CME-75 Truck (Rig Surveyed Out 4/2014)	5677	79	1.32	4/30/2009 HET Report
CME-750 A/T	6463	81	1.35	4/30/2009 HET Report
	6463	77	1.28	4/26/2013 HET Report
	6463	75	1.25	5/23/2014 HET Report
CME-85 Truck	7388	68	1.13	10/28/2009 HET Report
	7388	70	1.16	4/26/2013 HET Report
	7388	82	1.37	2/26/2015 HET Report

NYSDOT: Energy Correction for SPT

8.4.1 SPT Blow Count Corrections

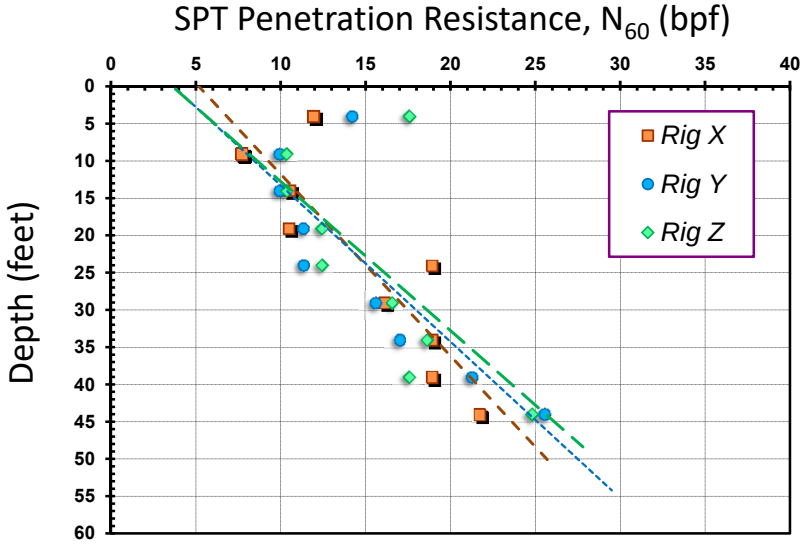
Geotechnical engineering practice which utilizes soil information based on SPT correlations must keep in mind that such correlations are generally based on a hammer impact efficiency of 60% at shallow overburden conditions. Therefore, blow count values should always be corrected to N_{60} values.

ADSC-ASCE-FHWA Load Tests at GT



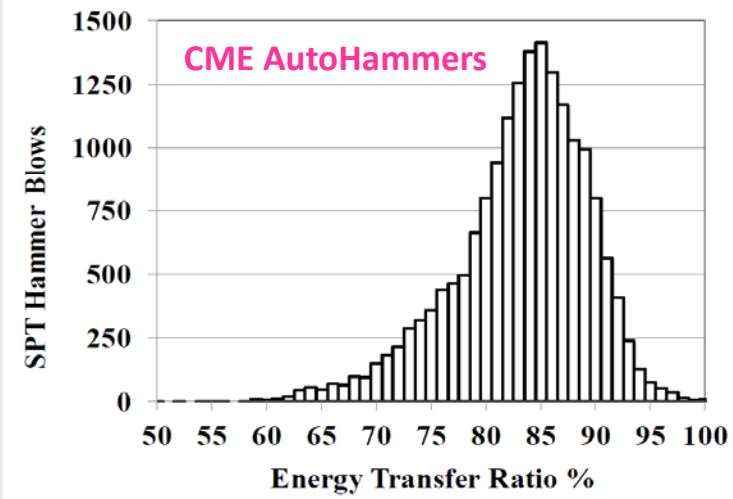
ADSC-ASCE-FHWA Load Tests at GT

CORRECTED USING ASSUMED ENERGY RATIOS



DISTRIBUTION OF ETR (HAMMER BLOWS)

Anderson (2014)



SPT AutoHammers

Roschen



CME 75



GeoProbe



Diedrich



Atlas



GeoProbe



Diedrich



CME 45b



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Calibration of SPT Energy - Auto Hammers

Manufacturer Type	ID No.	Mean Energy Ratio (%)	Reference
Diedrich D-120	ID 26	46	UDOT
Diedrich D-50	321870551	56	GRL
CME 850	ID 21	62.7	UDOT
BK-81 w/ AW-J rods	B2	68.6	ASCE
Mobile B-80	ID 18	70.4	UDOT
SK w/ CME hammer	B6	72.9	ASCE
Diedrich D50	UF5	76	UF
CME 55	UF2	78.4	FDOT
CME 850	296002	79	GRL
CME 45	UF1	80.7	UF
CME 85	UF4	81.2	UF
CME 75 w/ AW-J rods	A3	81.4	ASCE
CME 75	UF3	83.1	UF
CME 750	ID 4	86.6	UDOT
Mobile B-57	DR-35	93	GRL
CME 75 rig	ID 10	94.6	UDOT

Factor of 2.1

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Standard Penetration Test (SPT)
Conclusions

- SPT N-values per ASTM D 1586 are highly variable, mostly due to differences in hammer energy efficiency
- Raw N defies the spirit and intentions of AASHTO LRFD: i.e., high reliability, lower risk, economy
- Actual Energy Rating (ER) measurements must be made per ASTM D 4633
- ER should be obtained on each rig (at least once)
- Corrected SPT N_{60} useful as an index value in geotechnical explorations

Corrections to SPT N-value

Effect	Variable	Term	Value
Overburden Stress	σ_{vo}'	C_N	$(P_a/\sigma_{vo}')^{0.5}$ but ≤ 2
Energy Ratio[1]	· Safety Hammer · Donut Hammer · Automatic Hammer	C_E	0.6 to 0.85 0.3 to 0.6 0.85 to 1.0
Borehole Diameter	· 65 to 115 mm · 150 mm · 200 mm	C_B	1.00 1.05 1.15
Sampling Method	· Standard sampler · Sampler without liner	C_S	1.0 1.1 to 1.3
Rod Length	· 10 m to 30 m · 6 to 10 m · 4 to 6 m · 3 to 4 m	C_R	1.0 0.95 0.85 0.75
Particle Size	Median Grain Size (D_{50}) of Sand in mm	C_P	60 + 25 log D_{50}
Aging	Time (t) in years since deposition	C_A	1.2 + 0.05 log (t/100)
Overconsolidation	OCR	C_{OCR}	$OCR^{0.2}$

[1] Obtain by energy measurement per ASTM D4633

Corrections to SPT N-value

- $N_{measured}$ = Raw SPT Resistance (ASTM D 1586).
- N_{60} = (ER/60) $N_{measured}$ = Energy-Corrected N Value where ER = energy ratio (ASTM D 4633). Note: 30% < ER < 100% with average ER = 60% in the U.S.
- $N_{60} \approx C_E C_B C_S C_R N_{meas}$ = Estimated corrected N
- $(N_1)_{60} = C_N N_{60}$ = Energy-Corrected SPT Value normalized to an effective overburden stress of one atmosphere: $(N_1)_{60} = (N_{60})/(\sigma_{vo}')^{0.5}$ with stress given in atm. (Note: 1 atm = 1 bar = 100 kPa = 1 tsf).

CONE PENETRATION TESTING (CPT)



CONE PENETRATION TESTING (CPT)

- The cone penetration test is quickly becoming the most popular type of in-situ test because it is fast, economical, and provides continuous profiling of geostratigraphy and soil properties evaluation.

CONE PENETRATION TESTING (CPT)

- The test is performed according to ASTM D-3441 (mechanical systems) and ASTM D 5778 (electric and electronic systems) and consists of pushing a cylindrical steel probe into the ground at a constant rate of 20 mm/s and measuring the resistance to penetration.

CONE PENETRATION TESTING (CPT)

- The standard penetrometer has a conical tip with 60° angle apex, 35.7-mm diameter body (10-cm^2 projected area), and 150-cm^2 friction sleeve.

CONE PENETRATION TESTING (CPT)

- The measured point or tip resistance is designated qc and the measured side or sleeve resistance is fs.
- The ASTM standard also permits a larger 43.7-mm diameter shell (15-cm^2 tip and 200-cm^2 sleeve).

CONE PENETRATION TESTING (CPT)

- The CPT can be used in very soft clays to dense sands, yet is not particularly appropriate for gravels or rocky terrain.

CONE PENETRATION TESTING (CPT)

- As the test provides more accurate and reliable numbers for analysis, yet no soil sampling, it provides an excellent complement to the more conventional soil test boring with SPT measurements.

CONE PENETRATION TESTING *ADVANTAGES*

- Fast and continuous profiling
- Economical and productive
- Results not operator-dependent
- Strong theoretical basis in interpretation
- Particularly suitable for soft soils

CONE PENETRATION TESTING DISADVANTAGES

- High capital investment
- Requires skilled operator to run
- Electronic drift, noise, and calibration.
- No soil samples are obtained.
- Unsuitable for gravel or boulder deposits





Cone Penetrometers





- Electronic Steel Probes with 60° Apex Tip
- ASTM D 5778 Procedures
- Hydraulic Push at 20 mm/s
- No Boring, No Samples, No Cuttings, No Spoil
- Continuous readings of stress, friction, pressure

Cone Penetration Tests (CPT)

Cone Trucks







Mobile 25-tonne rigs with enclosed cabins to allow testing under all weather conditions

CONE PENETRATION TESTING

- Most electric/electronic cones require a cable that is threaded through the rods to connect with the power supply and data acquistion system at the surface.

CONE PENETRATION TESTING

- An analog-digital converter and pentium notebook are sufficient for collecting data at approximate 1-sec intervals.

CONE PENETRATION TESTING

- Depths are monitored using either a potentiometer (wire-spooled LVDT), depth wheel that the cable passes through, or ultrasonics sensor.

CONE PENETRATION TESTING

- Systems can be powered by voltage using either generator (AC) or battery (DC), or alternatively run on current.

Corrections to CPT

- Tip Stress correction for porewater pressures on unequal areas – Important in Intact Clays & Silts
- Sleeve Friction correction for porewater pressures – Use equal end areas on friction sleeve
- Baseline corrections – Obtain before & after sounding

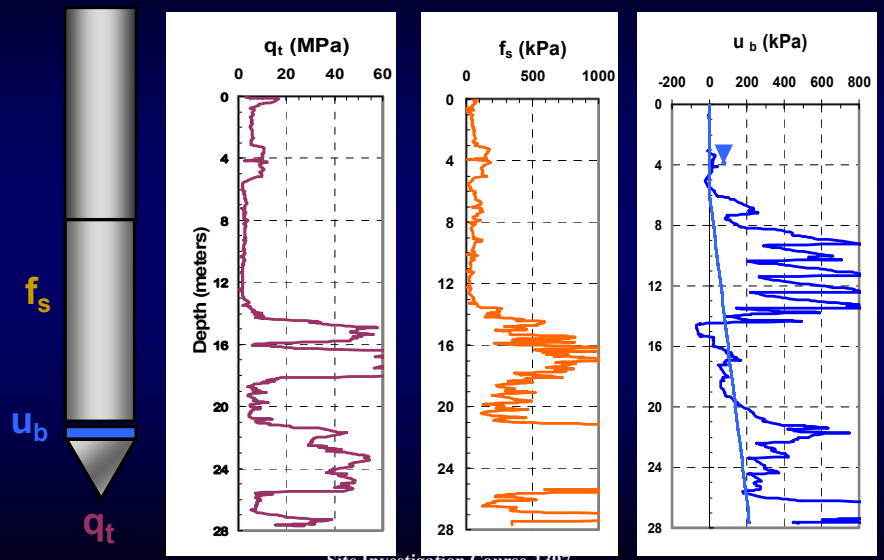
Anchored Cone Rig

Mud Island, Downtown Memphis, TN

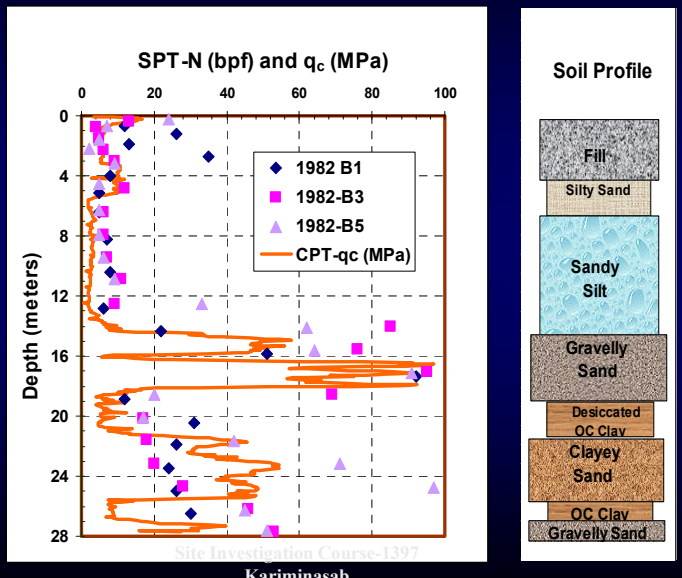


- 6-tonne Geostar truck with 20-tonne hydraulic pushing system
- No special license
- Twin earth anchors
- Has penetrated to depths over 32+ meters at sites in SC, AL, MO, TN, & AL

CPT Profile, Downhole Memphis



Comparison CPT and SPT Downtown Memphis



Shelby Tube



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Triaxial Shear Test

Specimen preparation (undisturbed sample)



Sampling tubes



Sample extruder

Triaxial Shear Test

Specimen preparation (undisturbed sample)



Edges of the sample are carefully trimmed



Setting up the sample in the triaxial cell

Triaxial Shear Test

Specimen preparation (undisturbed sample)



Sample is covered with a rubber membrane and sealed



Cell is completely filled with water

Triaxial Shear Test

Specimen preparation (undisturbed sample)



Proving ring to measure the deviator load

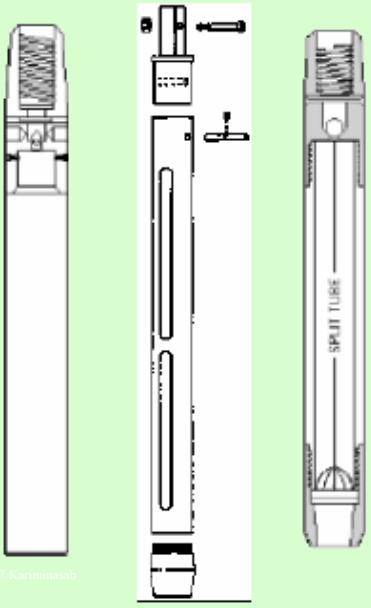
Dial gauge to measure vertical displacement

Power-Driven Sampling

- **Open Tube Samplers (~0.5m length)**
  - Thin-walled Samplers (Shelby Tubes etc)
- **Piston Samplers (~ 0.5m length)**
  - Stationary / Retracted / Free Piston Samplers
- **Continuous Samplers (up to 8m length)**
  - Swedish-Foil / Delft Continuous Samplers
  - Hollow Stem Auger
- **Single Tube Core Barrels (up to 3m length)**
  - Conventional Cores
- **Double and Triple Tube Core Barrels (up to 3m length)**
  - Denison / Christiansen / Pitcher Core Barrels

Split Spoons and Solid Barrels

- Split-spoon samplers used for cohesive soils
- Split-spoon allow the core to be extracted in an undisturbed state
- Solid-barrel samplers often require extrusion of the sample with a piston.



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SOILMOISTURE

How to Use the 0200 Soil Core Sampler for Undisturbed Sampling

Split Spoons

- Split spoons provide samples from cohesive soils. Solid barrels are more appropriate in sand, silts, and clays.
- Split spoons are tubes constructed of high strength alloy steel with a tongue and groove arrangement running the length of the tube, allowing it to be split in half.
- The two halves are held together by a threaded drive head assembly at the top, and a hardened shoe at the bottom, with a beveled cutting tip.

Split Spoons

- The sampler is driven by a 140-pound weight dropped through a 30-inch interval.
- When the split spoon is brought to the surface, it is disassembled and the core removed.
- Barrel samplers are similar to split spoons except they can not be taken apart. A core extruder might be required to remove the core from the barrel.

Split Spoons

- A series of consecutive cores may be extracted with a split-spoon sampler to give a complete soil column profile, or an auger may be used to drill down to the desired depth for sampling.
- The split spoon is then driven to its sampling depth through the bottom of the augured hole and the core extracted