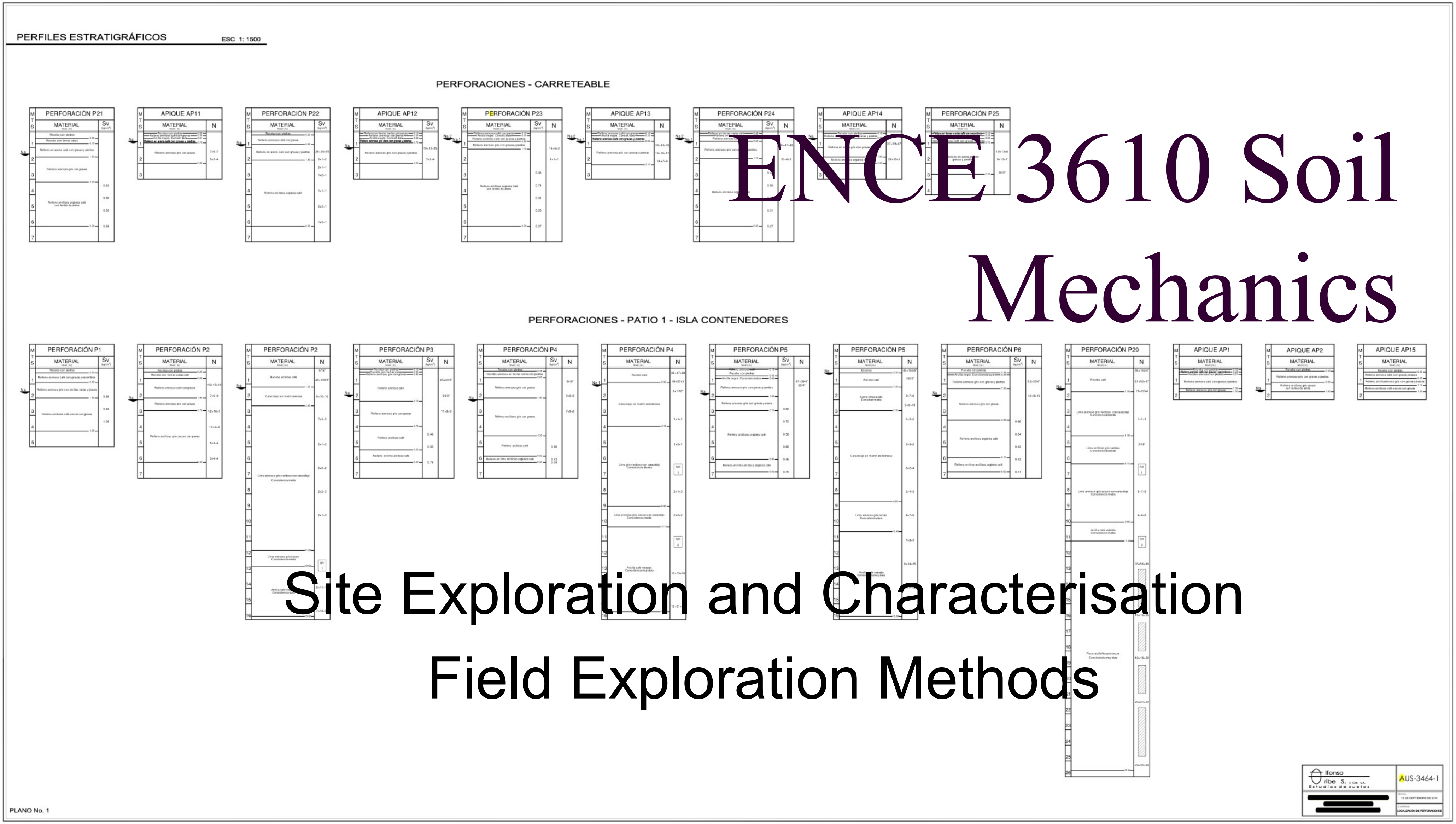


ENCE 3610 Soil Mechanics

Site Exploration and Characterisation

Field Exploration Methods

Geotechnical Involvement in Project Phases

- Planning
- Design Alternatives
- Preparation of Detailed Plans
- Final Design
- Construction
- Post Construction

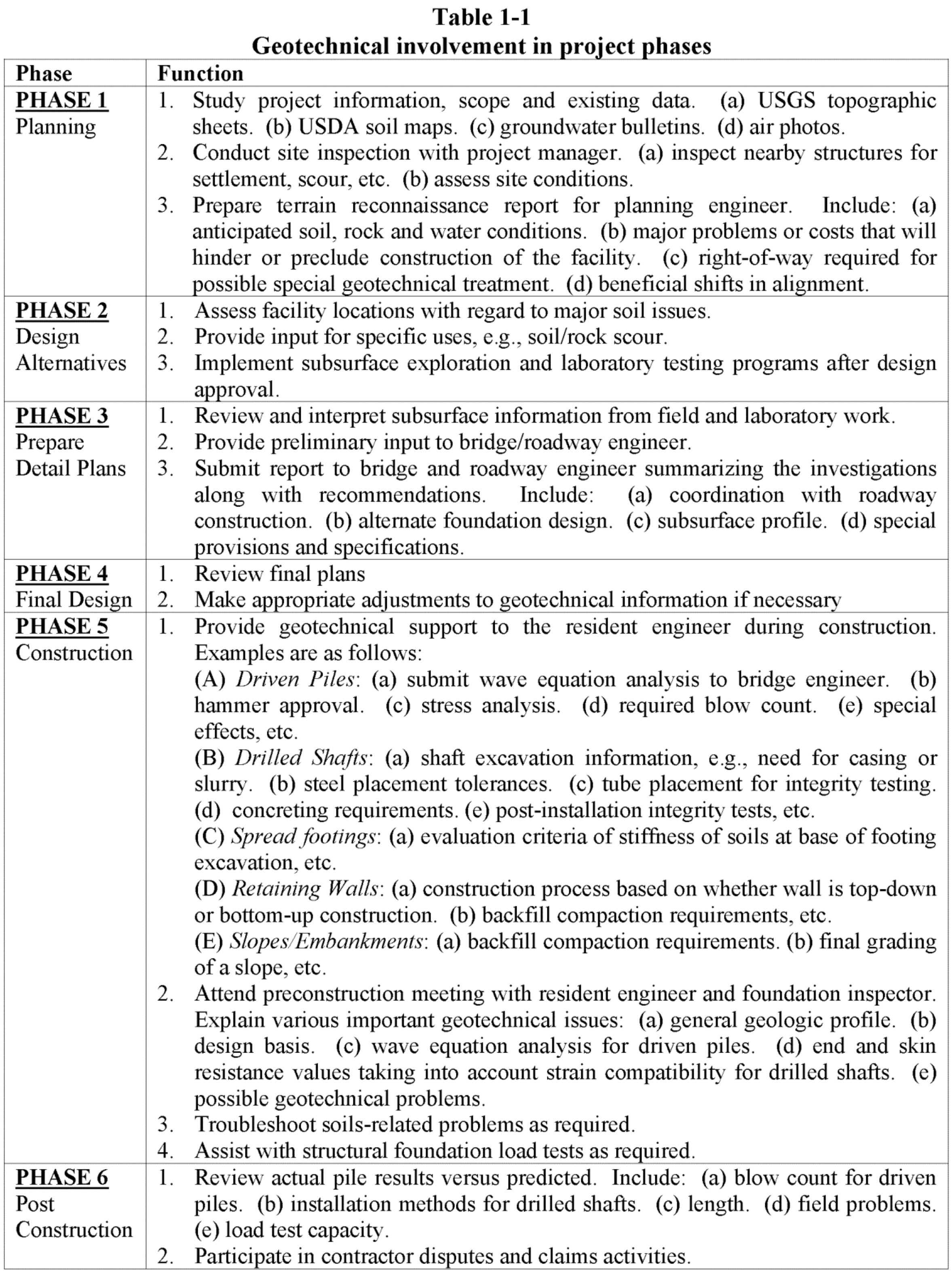


Table 1-1
Geotechnical involvement in project phases

Phase	Function
PHASE 1 Planning	1. Study project information, scope and existing data. (a) USGS topographic sheets. (b) USDA soil maps. (c) groundwater bulletins. (d) air photos. 2. Conduct site inspection with project manager. (a) inspect nearby structures for settlement, scour, etc. (b) assess site conditions. 3. Prepare terrain reconnaissance report for planning engineer. Include: (a) anticipated soil, rock and water conditions. (b) major problems or costs that will hinder or preclude construction of the facility. (c) right-of-way required for possible special geotechnical treatment. (d) beneficial shifts in alignment.
PHASE 2 Design Alternatives	1. Assess facility locations with regard to major soil issues. 2. Provide input for specific uses, e.g., soil/rock scour. 3. Implement subsurface exploration and laboratory testing programs after design approval.
PHASE 3 Prepare Detail Plans	1. Review and interpret subsurface information from field and laboratory work. 2. Provide preliminary input to bridge/roadway engineer. 3. Submit report to bridge and roadway engineer summarizing the investigations along with recommendations. Include: (a) coordination with roadway construction. (b) alternate foundation design. (c) subsurface profile. (d) special provisions and specifications.
PHASE 4 Final Design	1. Review final plans 2. Make appropriate adjustments to geotechnical information if necessary
PHASE 5 Construction	1. Provide geotechnical support to the resident engineer during construction. Examples are as follows: (A) *Driven Piles*: (a) submit wave equation analysis to bridge engineer. (b) hammer approval. (c) stress analysis. (d) required blow count. (e) special effects, etc. (B) *Drilled Shafts*: (a) shaft excavation information, e.g., need for casing or slurry. (b) steel placement tolerances. (c) tube placement for integrity testing. (d) concreting requirements. (e) post-installation integrity tests, etc. (C) *Spread footings*: (a) evaluation criteria of stiffness of soils at base of footing excavation, etc. (D) *Retaining Walls*: (a) construction process based on whether wall is top-down or bottom-up construction. (b) backfill compaction requirements, etc. (E) *Slopes/Embankments*: (a) backfill compaction requirements. (b) final grading of a slope, etc. 2. Attend preconstruction meeting with resident engineer and foundation inspector. Explain various important geotechnical issues: (a) general geologic profile. (b) design basis. (c) wave equation analysis for driven piles. (d) end and skin resistance values taking into account strain compatibility for drilled shafts. (e) possible geotechnical problems. 3. Troubleshoot soils-related problems as required. 4. Assist with structural foundation load tests as required.
PHASE 6 Post Construction	1. Review actual pile results versus predicted. Include: (a) blow count for driven piles. (b) installation methods for drilled shafts. (c) length. (d) field problems. (e) load test capacity. 2. Participate in contractor disputes and claims activities.

Overview of Site Exploration

- Planning for Field Investigations
- Exploration Phase
    - Reconnaissance/ Feasibility
    - Preliminary Exploration
    - Detailed Exploration
- Construction/Post Construction Phases

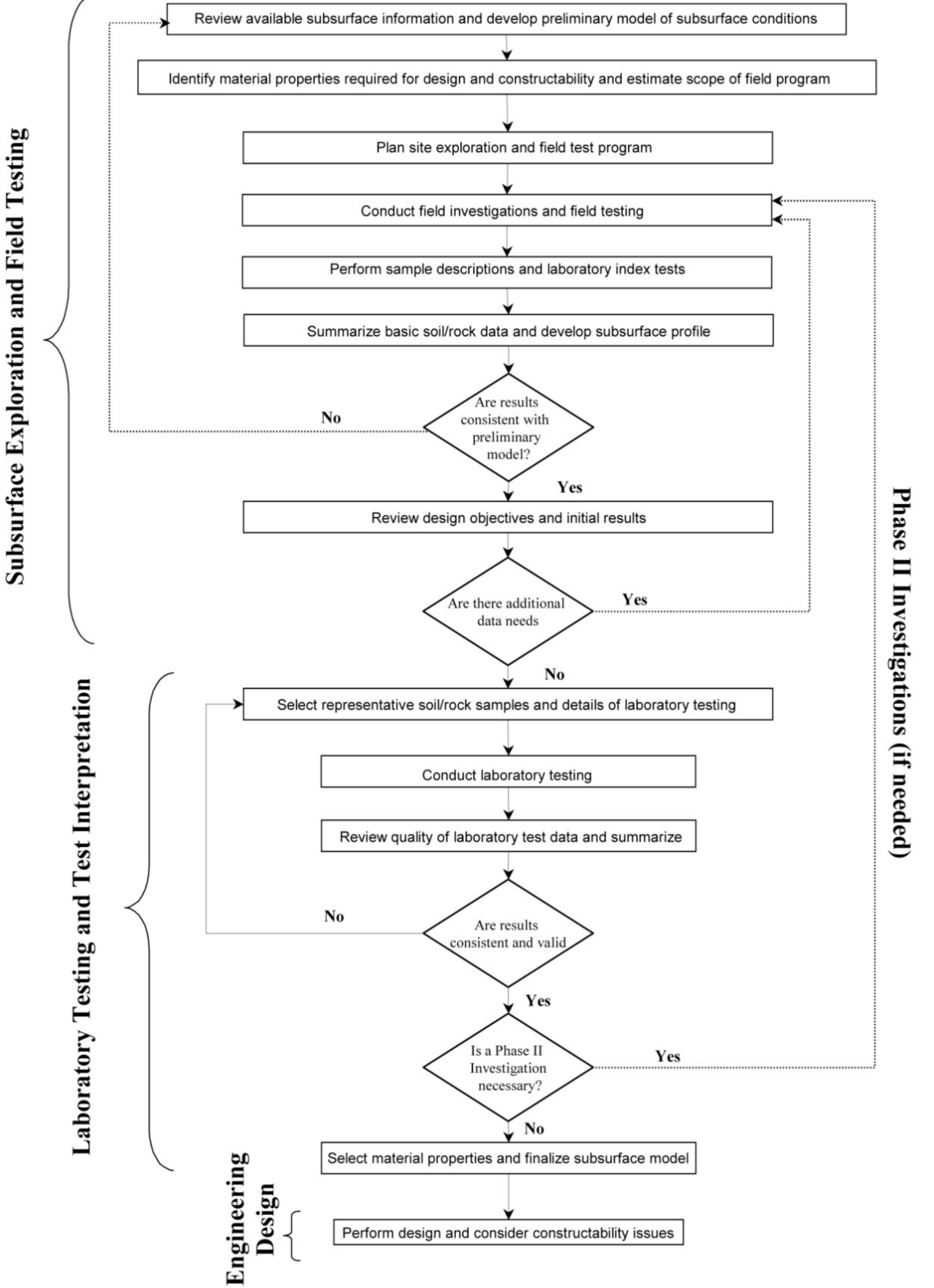


Figure 3-1. Recommended process for developing subsurface model for engineering design (FHWA, 2002a).

Planning for Field Investigations

- The initial phase of field investigations should consist of detailed review of geological conditions at the site and in its general environs. This should include a desktop study of available data including remote sensing imagery, aerial photography, and a field reconnaissance.
- To the extent possible, borings should be supplemented by lower cost exploration techniques such as test pits, probes, seismic refraction surveys, and electrical resistivity surveys.

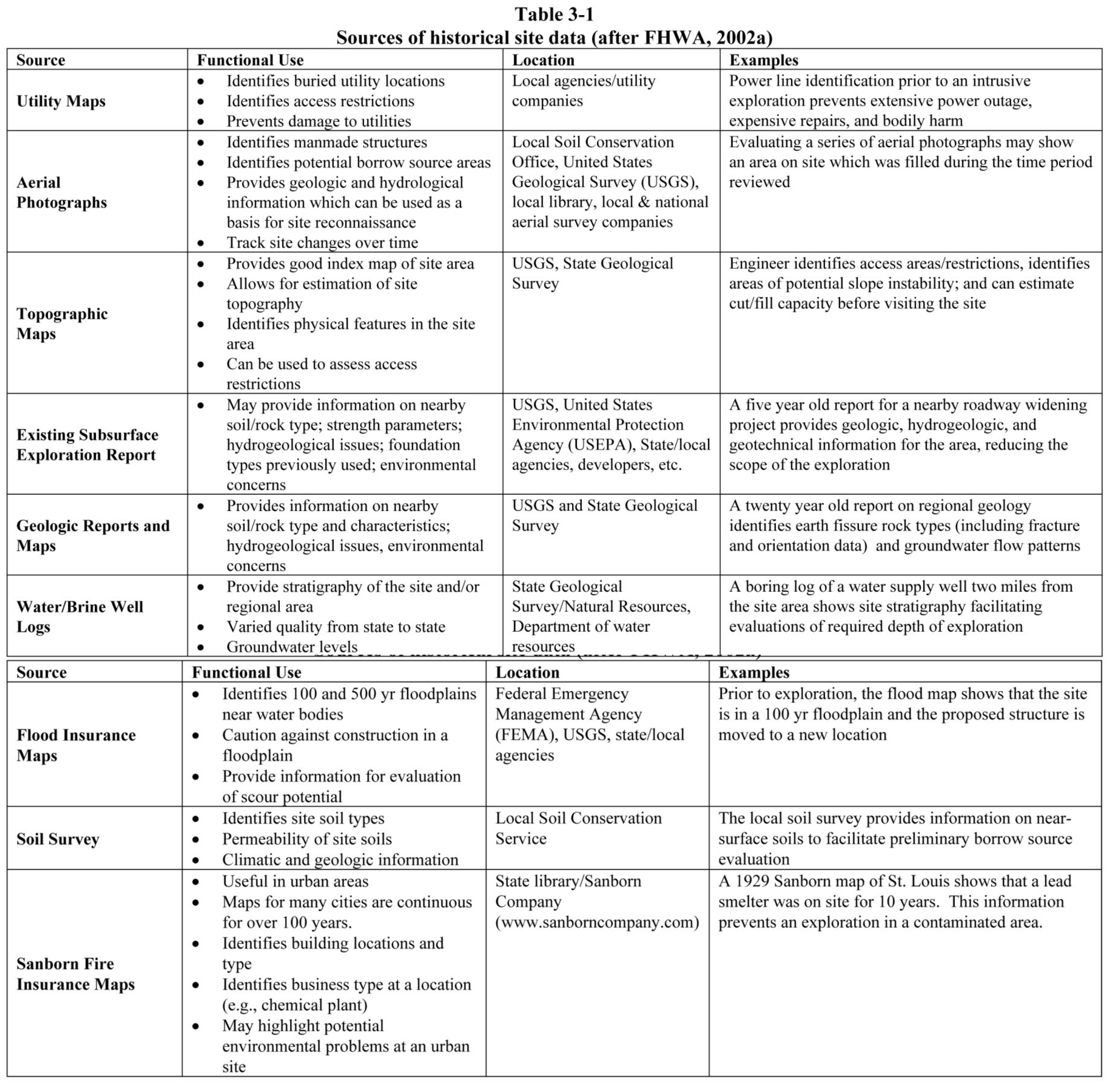


Table 3-1
Sources of historical site data (after FHWA, 2002a)

Source	Functional Use	Location	Examples
Utility Maps	• Identifies buried utility locations • Identifies access restrictions • Prevents damage to utilities	Local agencies/utility companies	Power line identification prior to an intrusive exploration prevents extensive power outage, expensive repairs, and bodily harm
Aerial Photographs	• Identifies manmade structures • Identifies potential borrow source areas • Provides geologic and hydrological information which can be used as a basis for site reconnaissance • Track site changes over time	Local Soil Conservation Office, United States Geological Survey (USGS), local library, local & national aerial survey companies	Evaluating a series of aerial photographs may show an area on site which was filled during the time period reviewed
Topographic Maps	• Provides good index map of site area • Allows for estimation of site topography • Identifies physical features in the site area • Can be used to assess access restrictions	USGS, State Geological Survey	Engineer identifies access areas/restrictions, identifies areas of potential slope instability; and can estimate cut/fill capacity before visiting the site
Existing Subsurface Exploration Report	• May provide information on nearby soil/rock type; strength parameters; hydrogeological issues; foundation types previously used; environmental concerns	USGS, United States Environmental Protection Agency (USEPA), State/local agencies, developers, etc.	A five year old report for a nearby roadway widening project provides geologic, hydrogeologic, and geotechnical information for the area, reducing the scope of the exploration
Geologic Reports and Maps	• Provides information on nearby soil/rock type and characteristics; hydrogeological issues, environmental concerns	USGS and State Geological Survey	A twenty year old report on regional geology identifies earth fissure rock types (including fracture and orientation data) and groundwater flow patterns
Water/Brine Well Logs	• Provide stratigraphy of the site and/or regional area • Varied quality from state to state • Groundwater levels	State Geological Survey/Natural Resources, Department of water resources	A boring log of a water supply well two miles from the site area shows site stratigraphy facilitating evaluations of required depth of exploration
Flood Insurance Maps	• Identifies 100 and 500 yr floodplains near water bodies • Caution against construction in a floodplain • Provide information for evaluation of scour potential	Federal Emergency Management Agency (FEMA), USGS, state/local agencies	Prior to exploration, the flood map shows that the site is in a 100 yr floodplain and the proposed structure is moved to a new location
Soil Survey	• Identifies site soil types • Permeability of site soils • Climatic and geologic information	Local Soil Conservation Service	The local soil survey provides information on near-surface soils to facilitate preliminary borrow source evaluation
Sanborn Fire Insurance Maps	• Useful in urban areas • Maps for many cities are continuous for over 100 years. • Identifies building locations and type • Identifies business type at a location (e.g., chemical plant) • May highlight potential environmental problems at an urban site	State library/Sanborn Company (www.sanborncompany.com)	A 1929 Sanborn map of St. Louis shows that a lead smelter was on site for 10 years. This information prevents an exploration in a contaminated area.
]

Field Reconnaissance

- Inspection of nearby structures to determine their performance with the particular foundation type utilized. If settlement is suspected, the original structural plans should be reviewed and the structure surveyed by using the original benchmark.
- For water crossings, inspection of structural footings and the stream banks up and downstream for evidence of scour. Take careful note of the stream bed material. Often large boulders exposed in the stream but not encountered in the borings, are an indication of potential subsurface obstructions to pile installation.
- Recording the location, type, and depth of any existing structures or abandoned foundations that may infringe on the new highway facility.
- Relating site conditions to the proposed boring operations. Record potential problems with utilities (overhead and underground), site access, private property, or obstructions.

Objectives of Site Investigation Program

1. Determine stratigraphy.
   a. physical description and extent of each stratum.
   b. thickness and elevation of top and bottom of each stratum.

2. For fine-grained soils (each stratum) determine:
   a. natural moisture contents.
   b. Atterberg limits.
   c. stiffness.
   d. presence of organic materials.
   e. evidence of desiccation or previous soil disturbance, shearing, or slickensides.
   f. swelling characteristics.
   g. unconfined compressive strength - typically estimated from Standard Penetration Tests or Cone Penetration Tests.
   h. shear strength.
   i. compressibility.

3. For coarse-grained soils (each stratum) determine:
   a. in-situ density (average and range) typically determined from Standard Penetration Tests or Cone Penetration Tests.
   b. grain-size distributions (gradation).
   c. presence of organic materials.

4. Determine depth to ground water (for each aquifer if more than one is present).
   a. piezometric surface over site area: existing, past, and probable range in future (observe at several times).
   b. perched water table.

5. Determine depth to bedrock.
   a. depth over entire site.
   b. type of rock.
   c. extent and character of weathering.
   d. joints, including distribution, spacing, whether open or closed, and joint infilling.
   e. faults.
   f. solution effects in limestone or other soluble rocks.
   g. core recovery and soundness (RQD).
   h. hardness and strength.

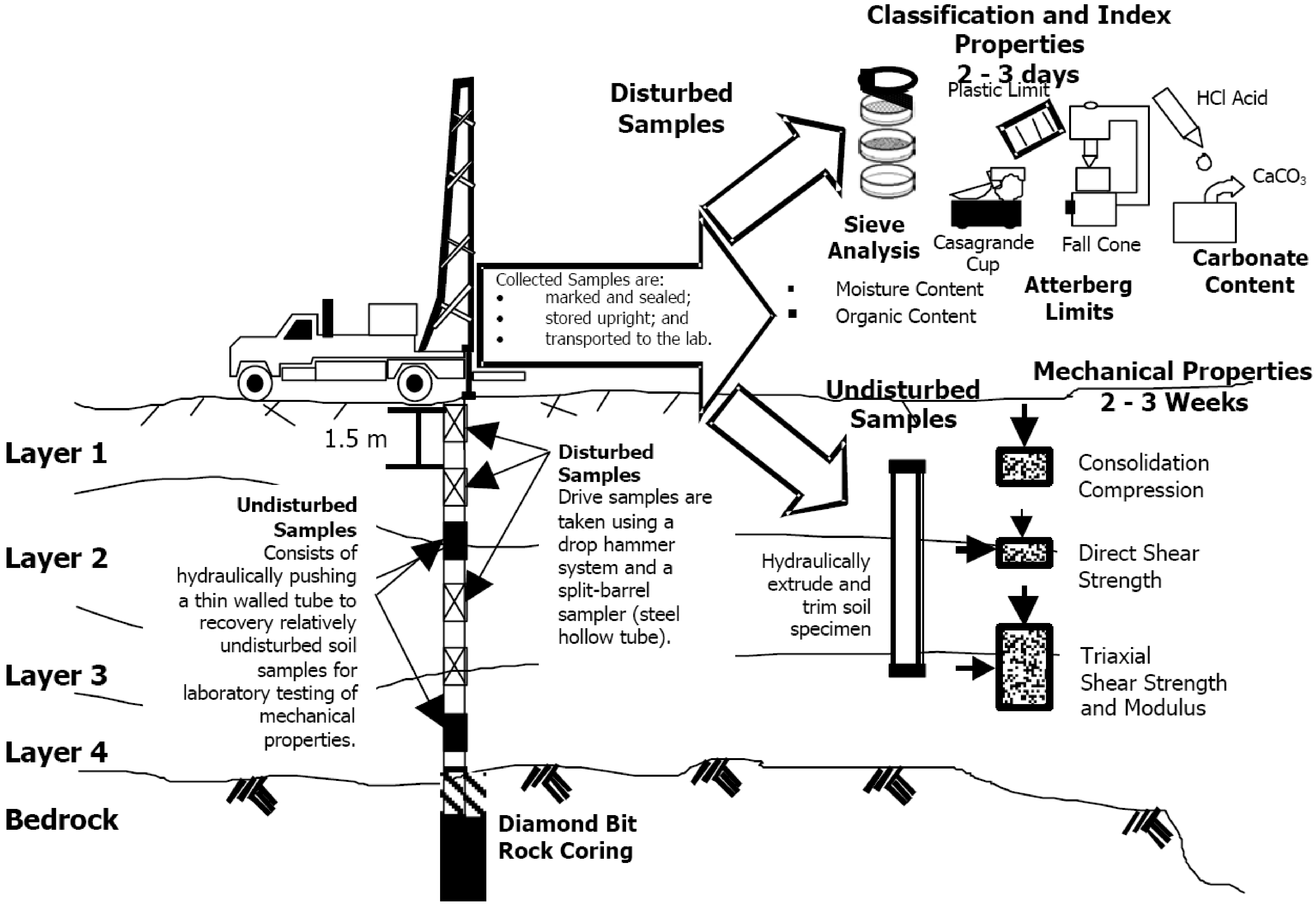


Figure 35. Traditional drilling, sampling, and laboratory testing of collected samples.

Reference Standards for Exploration Techniques

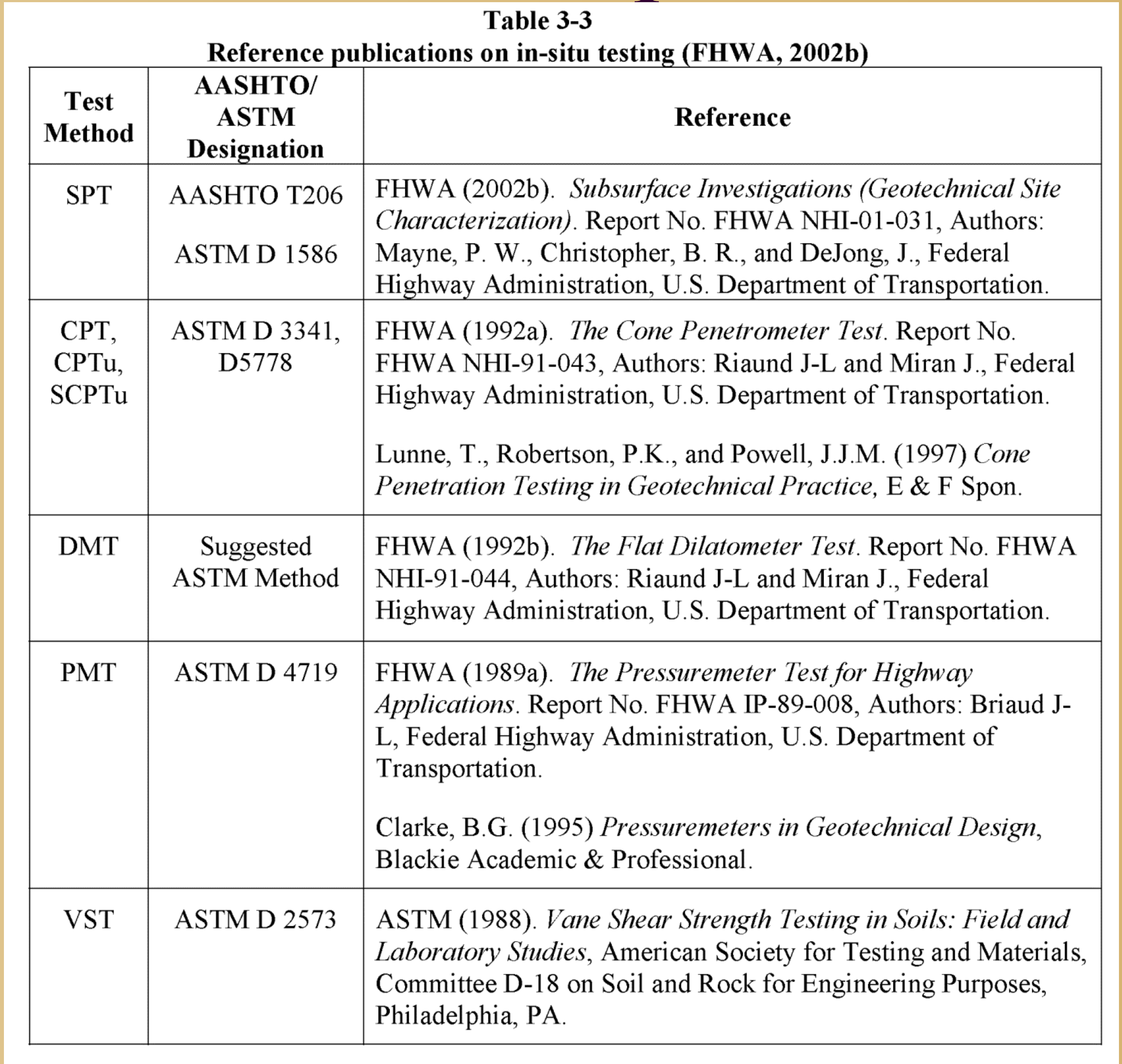


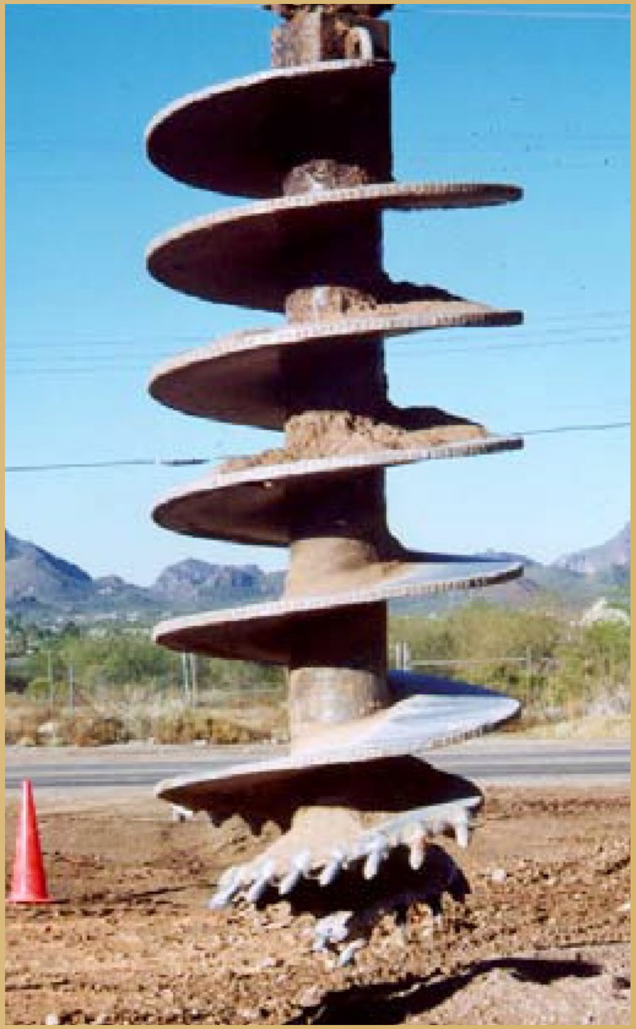
Table 3-3

Reference publications on in-situ testing (FHWA, 2002b)

Test Method	AASHTO/ ASTM Designation	Reference
SPT	AASHTO T206 ASTM D 1586	FHWA (2002b). *Subsurface Investigations (Geotechnical Site Characterization)*. Report No. FHWA NHI-01-031, Authors: Mayne, P. W., Christopher, B. R., and DeJong, J., Federal Highway Administration, U.S. Department of Transportation.
CPT, CPTu, SCPTu	ASTM D 3341, D5778	FHWA (1992a). *The Cone Penetrometer Test*. Report No. FHWA NHI-91-043, Authors: Riaund J-L and Miran J., Federal Highway Administration, U.S. Department of Transportation. Lunne, T., Robertson, P.K., and Powell, J.J.M. (1997) *Cone Penetration Testing in Geotechnical Practice*, E & F Spon.
DMT	Suggested ASTM Method	FHWA (1992b). *The Flat Dilatometer Test*. Report No. FHWA NHI-91-044, Authors: Riaund J-L and Miran J., Federal Highway Administration, U.S. Department of Transportation.
PMT	ASTM D 4719	FHWA (1989a). *The Pressuremeter Test for Highway Applications*. Report No. FHWA IP-89-008, Authors: Briaud J-L, Federal Highway Administration, U.S. Department of Transportation. Clarke, B.G. (1995) *Pressuremeters in Geotechnical Design*, Blackie Academic & Professional.
VST	ASTM D 2573	ASTM (1988). *Vane Shear Strength Testing in Soils: Field and Laboratory Studies*, American Society for Testing and Materials, Committee D-18 on Soil and Rock for Engineering Purposes, Philadelphia, PA.

Discontinuous or single flight auger borings and bucket auger borings.

- Types
  - Discontinuous flight augers have diameters ranging from 0.25 to 3 ft (0.075 to 1 m)
  - Bucket augers have diameters ranging from 1 to 8 ft (0.3 to 2.5 m).
- A casing is generally not used
- Depth Limitations
  - Not recommended for boreholes deeper than 35 ft (10 m), or where the hole may cave-in during the excavation of loose or soft soils, or when the boring is below the groundwater table.
  - In firm stiff clays, discontinuous auger borings can be performed to depths in excess of 35 ft (10 m).



Continuous flight auger borings

- Types of continuous flight augers
  - **Solid stem**
    - The solid stem auger must be removed from the borehole to allow access to the hole for insertion of sampling or testing devices.
    - Because the auger must be periodically removed from the borehole, a solid stem auger is not appropriate in sands and soft soils or in soil deposits where groundwater is close to the surface.
  - **Hollow stem.**
    - Has a circular hollow core that allows for sampling through the center of the auger.
    - Auger acts like a casing and allows for sampling in loose or soft soils or when the excavation is below the ground water table.
    - A plug is necessary when hollow stem augers are advanced to prevent cuttings from migrating through the hollow stem. The plug is removed to permit SPT sampling.
    - In loose sands and soft clays extending below the water table, drilling fluids are often used to minimize and mitigate disturbance effects and keep the hole open.

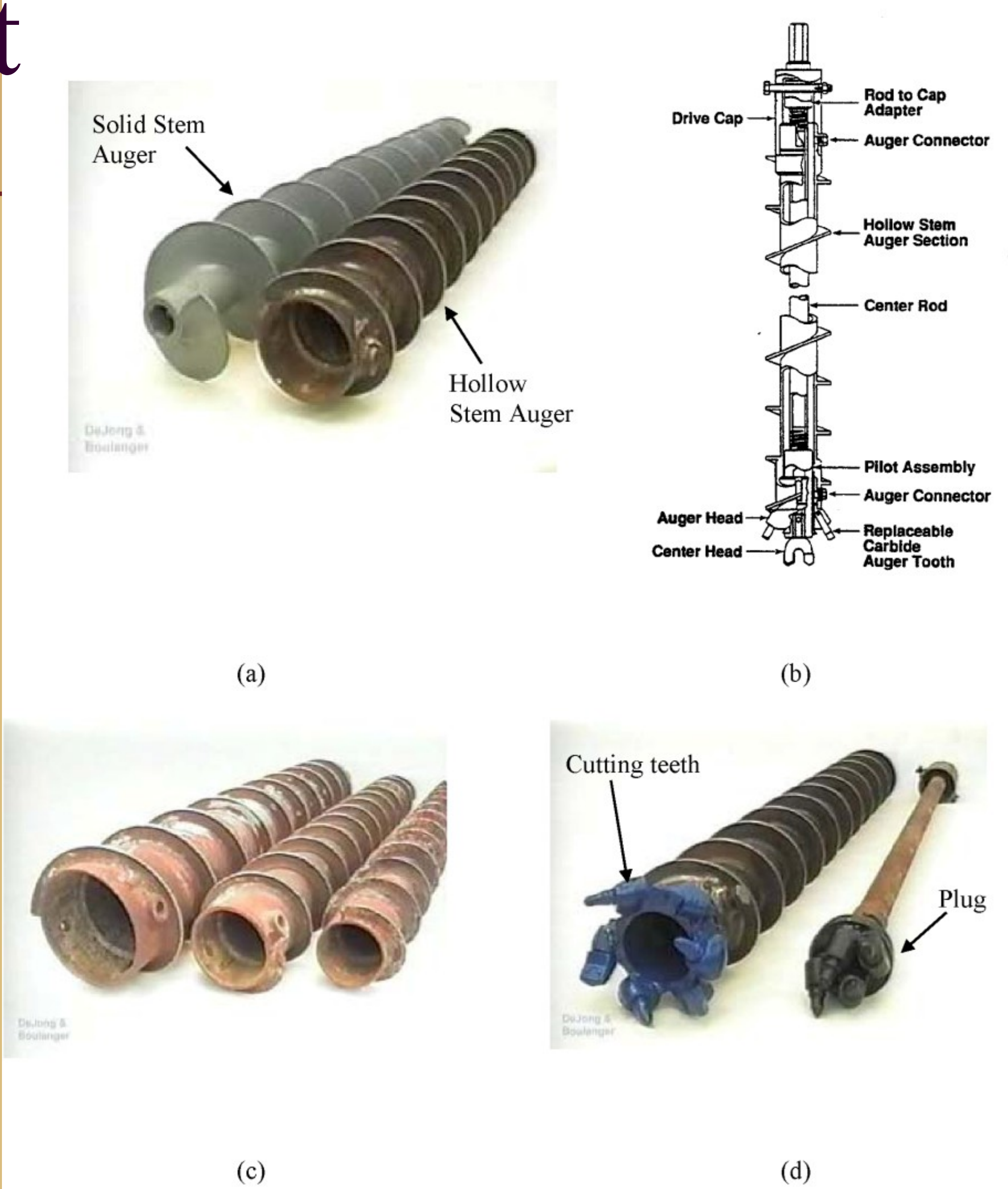


Figure 3-6. (a) Solid stem auger and hollow stem auger, (FHWA, 2002b) (b) Hollow stem auger components (ASTM D 4700), (c) Sizes of hollow stem auger flights (FHWA, 2002b), (d) Outer and inner assembly of hollow stem auger (FHWA, 2002b).

Wash Type Borings

- Wash-type borings use circulating drilling fluid (e.g., water or mud) to remove cuttings from the borehole.
- Cuttings are created by the chopping, twisting, and jetting action of the drill bit that breaks the soil or rock into small fragments.
- Tri-cone bits are often used in dense soil or soft rock. If bentonite or a polymeric drilling mud cannot be used to maintain an open borehole, casings are often used to prevent cave-in of the borehole.
- The use of casing will require a significant amount of additional time and effort but will result in a protected borehole.
- When drilling mud is used during subsurface boring, it will be difficult to classify the soil from the auger cuttings because of contamination with the mud. Also, the outside of samples may become coated with drilling mud.
- The properties of the drilling fluid and the quantity of water pumped through the drill bit will determine the size of particles that can be removed from the boring with the circulating fluid.
- In formations containing gravels, cobbles, or larger particles, coarse material may be left at the bottom of the boring.
- In these instances, cleaning the bottom of the boring with a larger diameter sampler (such as the 3 in (75 mm) OD split barrel sampler) may be needed to obtain a representative sample of the formation.

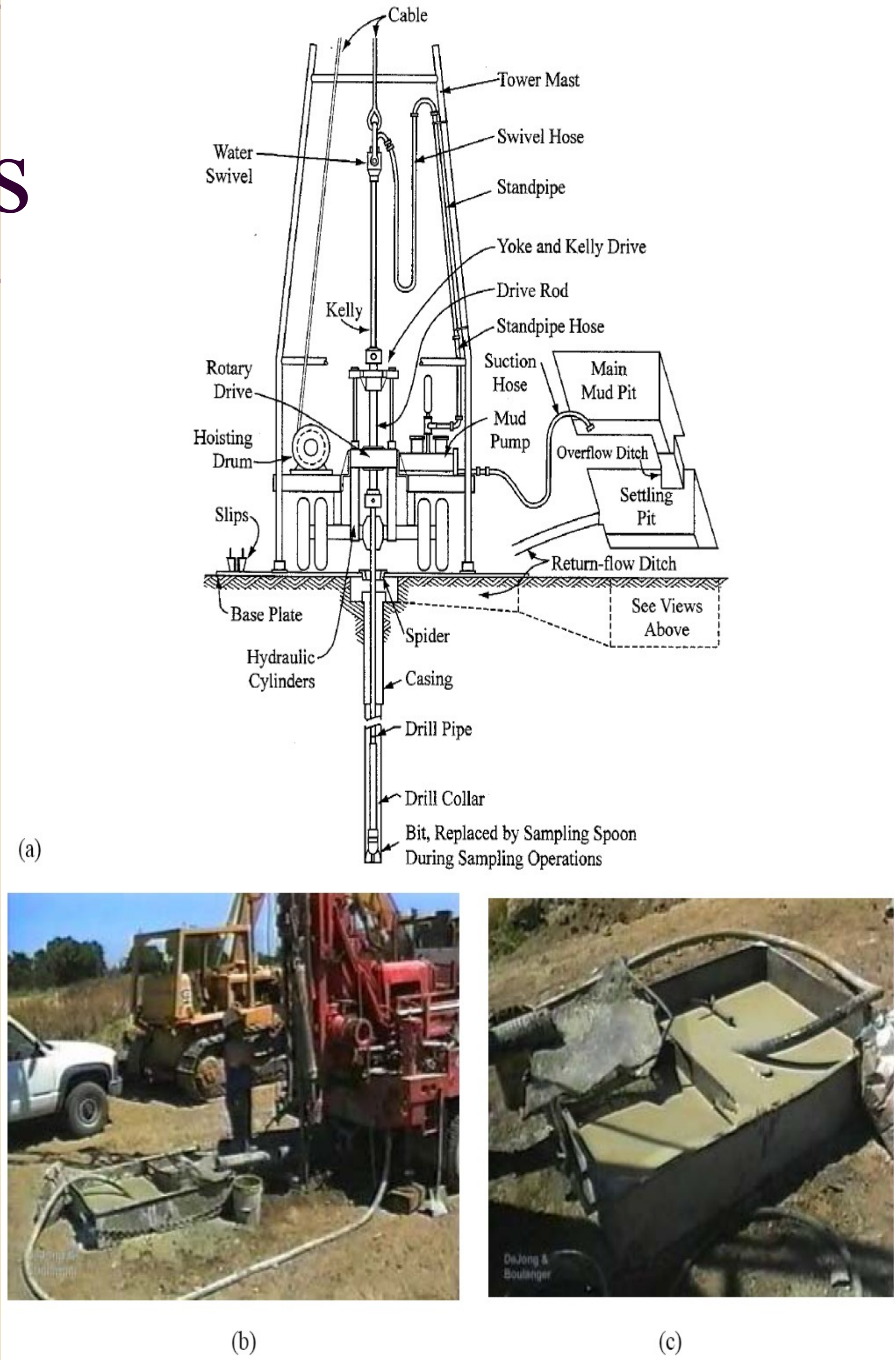


Figure 3-7. (a) Schematic of drilling rig for rotary wash methods (after Hvorslev, 1948), (b) Typical drilling configuration, (c) Settling basin (mud tank).

Soil Boring Methods

Table 3-4(a)

Soil and soft rock boring methods (FHWA, 2002a)

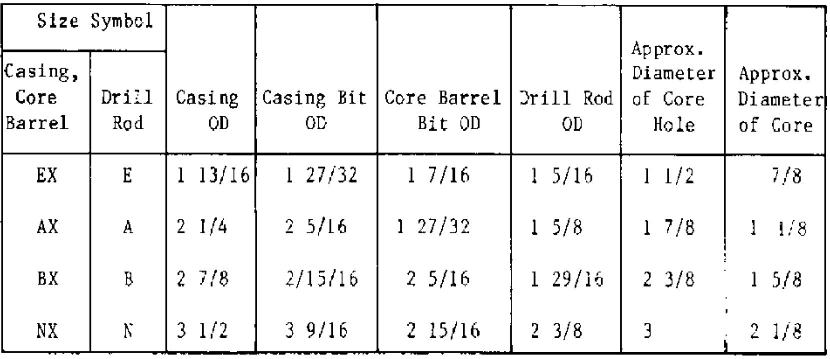
Method	Procedure	Applications	Limitations / Remarks
Auger boring (ASTM D 1452)	Dry hole drilled with hand or power auger; samples recovered from auger flights	In soil and soft rock; to identify geologic units and water content above water table	Soil and rock stratification destroyed; sample mixed with water below the water table
Hollow-stem auger boring	Hole advanced by hollow-stem auger; soil sampled below auger as in auger boring above	Typically used in soils that would require casing to maintain an open hole for sampling	Sample limited by larger gravel; maintaining hydrostatic balance in hole below water table is difficult
Wash-type boring	Light chopping and strong jetting of soil; cuttings removed by circulating fluid and discharged into settling tub	Soft to stiff cohesive materials and fine to coarse granular soils	Coarse material tends to settle to bottom of hole; should not be used in boreholes above water table where undisturbed samples are desired.
Becker Hammer Penetration Test (BPT)	Hole advanced using double acting diesel hammer to drive a 6.6-in (168 mm) double-walled casing into the ground. Several sizes are available.	Typically used in soils with gravel and cobbles; casing is driven open-ended if sampling of materials is desired	Skin friction of casing difficult to account for; unsure as to the repeatability of test
Bucket Auger boring	A 2 to 4 ft (0.6 to 1.2 m) diameter drilling bucket with cutting teeth is rotated and advanced. At the completion of each advancement, the bucket is retrieved from the boring and soil is emptied on the ground.	Most soils above water table; can dig harder soils than above types and can penetrate soils with cobbles and boulders if equipped with a rock bucket	Not applicable in running sands; used for obtaining large volumes of disturbed samples and where it is necessary to enter a boring to make observations

Rock Core Drilling

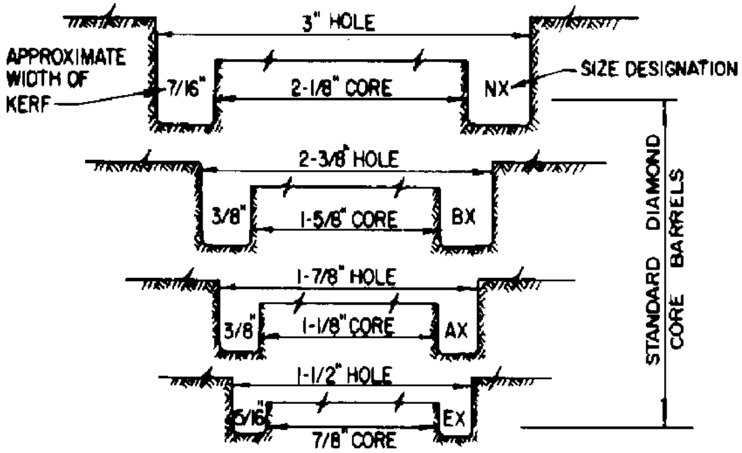
- Done with with either tungsten carbide or diamond core bits
- Use a double or triple tube core barrel when sampling weathered or fractured rock
- Used to determine Rock Quality Designation

(a) (b)

Figure 3-15. Double tube core barrel. (a) Outer barrel assembly (b) Inner barrel assembly (FHWA, 2002b).



Size Symbol							
Casing, Core Barrel	Drill Rod	Casing OD	Casing Bit OD	Core Barrel Bit OD	Drill Rod OD	Approx. Diameter of Core Hole	Approx. Diameter of Core
EX	E	1 13/16	1 27/32	1 7/16	1 5/16	1 1/2	7/8
AX	A	2 1/4	2 5/16	1 27/32	1 5/8	1 7/8	1 1/8
BX	B	2 7/8	2/15/16	2 5/16	1 29/16	2 3/8	1 5/8
NX	N	3 1/2	3 9/16	2 15/16	2 3/8	3	2 1/8



STANDARDS BY NATIONAL BUREAU OF STANDARDS DIAMOND CORE DRILL MANUFACTURERS.

FIGURE 2
Standard Sizes, in Inches, for Casings, Rods, Core Barrels, and Holes

Rock Boring

Table 3-4(b)
Rock core drilling methods (FHWA, 2002a)(1)

Method	Procedure	Type of sample	Applications	Limitations / Remarks
Rotary coring of rock (ASTM D 2113; AASHTO T 225)	Outer tube with diamond (or tungsten carbide) bit on lower end rotated to cut annular hole in rock; core protected by stationary inner tube; cuttings flushed upward by drill fluid	Rock cylinder 1 in to 4 in (25 to 100 mm) in diameter and as long as 10 ft (3 m), depending on rock soundness. Standard coring size is 2-1/8 in (54 mm) diameter.	To obtain continuous core in sound rock (percent of core recovered depends on fractures, rock variability, equipment, and driller skill)	Core lost in fracture or variable rock; blockage prevents drilling in badly fractured rock; dip of bedding and joint evident but not strike
Rotary coring of rock, wire line	Same as ASTM D 2113, but core and stationary inner tube retrieved from outer core barrel by lifting device or "overshot" suspended on thin cable (wire line) through special large-diameter drill rods and outer core barrel	Rock cylinder 1-1/8 in to 3-3/8 in (28 to 85 mm) wide and 5 ft to 10 ft (1.5 to 3 m) long	To recover core better in fractured rock which has less tendency for caving during core removal; to obtain much faster cycle of core recovery and resumption of drilling in deep holes	Core lost in fracture or variable rock; blockage prevents drilling in badly fractured rock; dip of bedding and joint evident but not strike
Rotary coring of swelling clay, soft rock	Similar to rotary coring of rock; swelling core retained by third inner plastic liner	Soil cylinder 1-1/8 in to 3-3/8 in (28 to 85 mm) wide and 2 ft to 5 ft (0.6 m to 1.5 m) long encased in plastic tube	In soils and soft rocks that swell or disintegrate rapidly in air (protected by plastic tube)	Sample smaller; equipment more complex than other soil sampling techniques

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(1) See Section 3.6.4 for additional discussion on types of core barrels (i.e., single-, double-, or triple-tube).

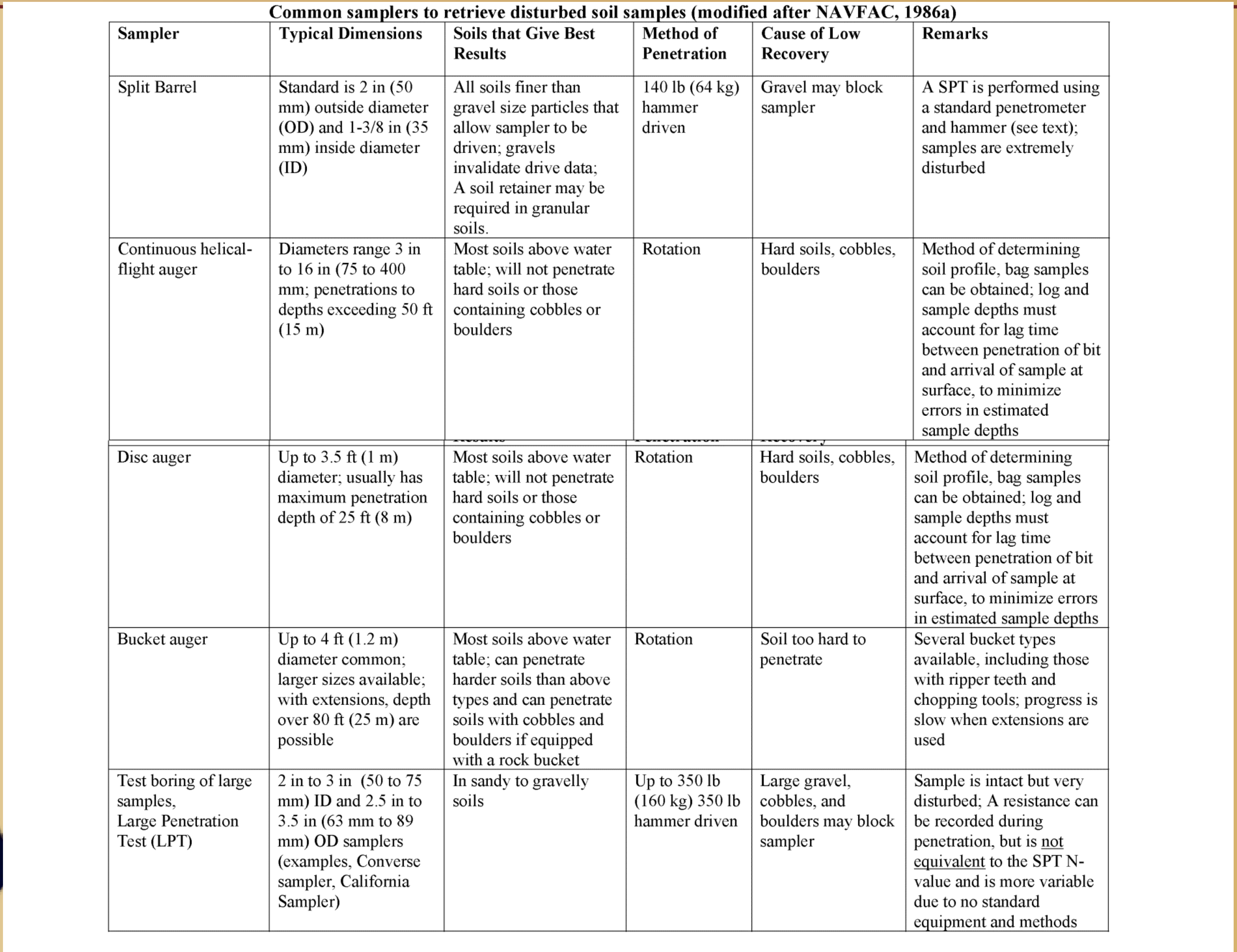
Disturbed and Undisturbed Samplers

- Disturbed Sampling
  - Provides a means to evaluate stratigraphy by visual examination and to obtain soil specimens for laboratory index testing.
  - Disturbed samples are usually collected using split-barrel samplers
  - Shallow disturbed samples can also be obtained by using hand augers and test pits.
  - Samples obtained via disturbed sampling methods are generally used for index property testing in the laboratory. They should not be used to prepare specimens for consolidation and strength tests.

Figure 3-8. Split barrel sampler.

- Undisturbed Sampling
- Undisturbed soil samples are required for performing laboratory strength and consolidation tests on cohesive soils having consistencies ranging from soft to stiff.
- High-quality samples for such tests are particularly important for approach embankments and for structural foundations and wall systems that may stress compressible strata.
- In reality, it is impossible to retrieve truly undisturbed samples since changes in the state of stress in the sample occur upon sampling and removal of the sample from depth.
- Due to cost and ease of use, the thin-walled Shelby tube is the most commonly used sampler for obtaining relatively undisturbed samples of soft to stiff fine-grained soils.

Types of Disturbed Samplers



Common samplers to retrieve disturbed soil samples (modified after NAVFAC, 1986a)

Sampler	Typical Dimensions	Soils that Give Best Results	Method of Penetration	Cause of Low Recovery	Remarks
Split Barrel	Standard is 2 in (50 mm) outside diameter (OD) and 1-3/8 in (35 mm) inside diameter (ID)	All soils finer than gravel size particles that allow sampler to be driven; gravels invalidate drive data; A soil retainer may be required in granular soils.	140 lb (64 kg) hammer driven	Gravel may block sampler	A SPT is performed using a standard penetrometer and hammer (see text); samples are extremely disturbed
Continuous helical-flight auger	Diameters range 3 in to 16 in (75 to 400 mm; penetrations to depths exceeding 50 ft (15 m)	Most soils above water table; will not penetrate hard soils or those containing cobbles or boulders	Rotation	Hard soils, cobbles, boulders	Method of determining soil profile, bag samples can be obtained; log and sample depths must account for lag time between penetration of bit and arrival of sample at surface, to minimize errors in estimated sample depths
Disc auger	Up to 3.5 ft (1 m) diameter; usually has maximum penetration depth of 25 ft (8 m)	Most soils above water table; will not penetrate hard soils or those containing cobbles or boulders	Rotation	Hard soils, cobbles, boulders	Method of determining soil profile, bag samples can be obtained; log and sample depths must account for lag time between penetration of bit and arrival of sample at surface, to minimize errors in estimated sample depths
Bucket auger	Up to 4 ft (1.2 m) diameter common; larger sizes available; with extensions, depth over 80 ft (25 m) are possible	Most soils above water table; can penetrate harder soils than above types and can penetrate soils with cobbles and boulders if equipped with a rock bucket	Rotation	Soil too hard to penetrate	Several bucket types available, including those with ripper teeth and chopping tools; progress is slow when extensions are used
Test boring of large samples, Large Penetration Test (LPT)	2 in to 3 in (50 to 75 mm) ID and 2.5 in to 3.5 in (63 mm to 89 mm) OD samplers (examples, Converse sampler, California Sampler)	In sandy to gravelly soils	Up to 350 lb (160 kg) 350 lb hammer driven	Large gravel, cobbles, and boulders may block sampler	Sample is intact but very disturbed; A resistance can be recorded during penetration, but is not equivalent to the SPT N-value and is more variable due to no standard equipment and methods

Plotting Atterberg Limits

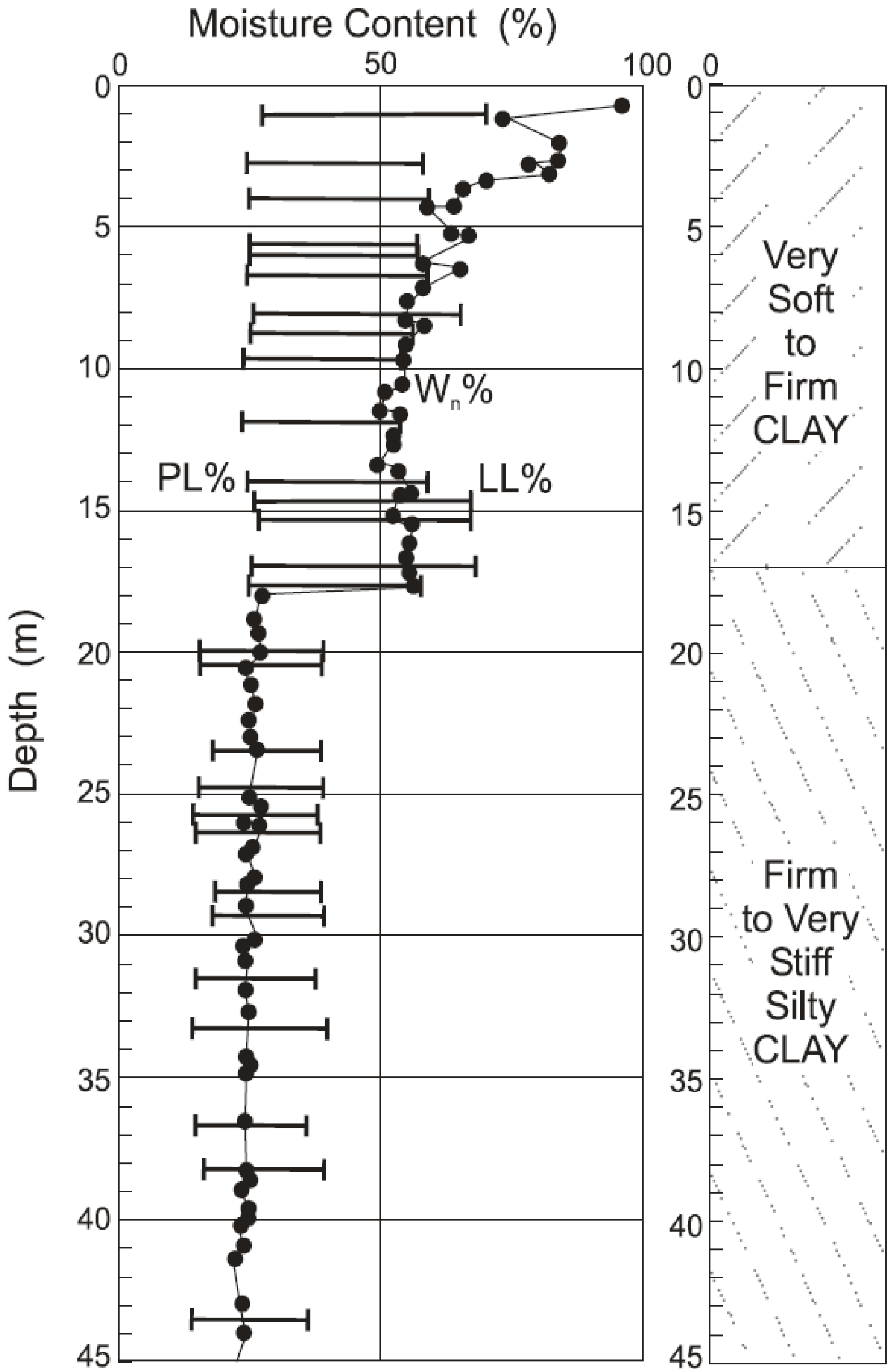


Figure 44. Summary plot of Atterberg limits data.

Samplers for Undisturbed Samples

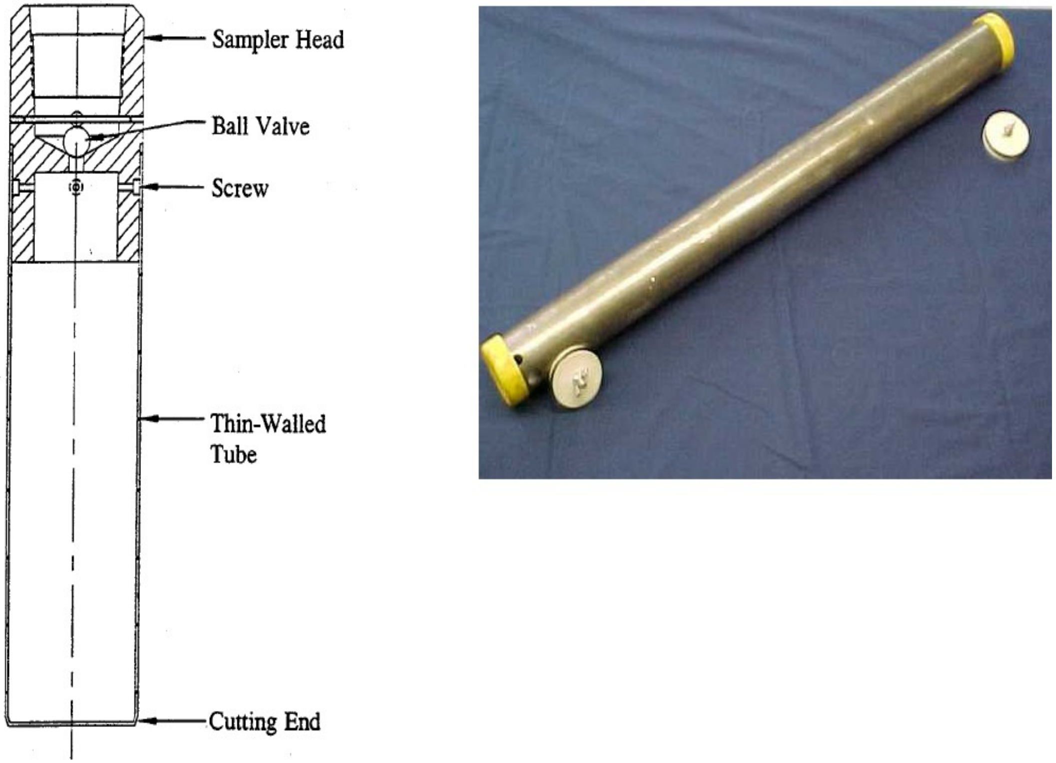


Figure 3-9. Schematic of thin-walled (Shelby) tube (after ASTM D 4700) and photo of tube with end caps (FHWA, 2002b).

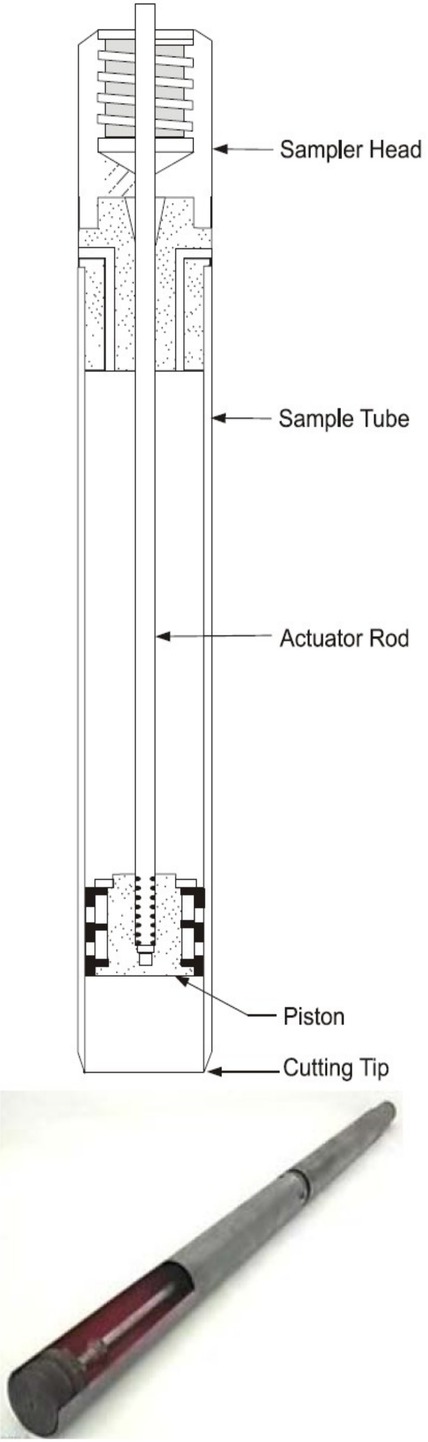


Figure 3-10. Stationary piston sampler schematic (after ASTM D 4700) and photo (FHWA, 2002b).

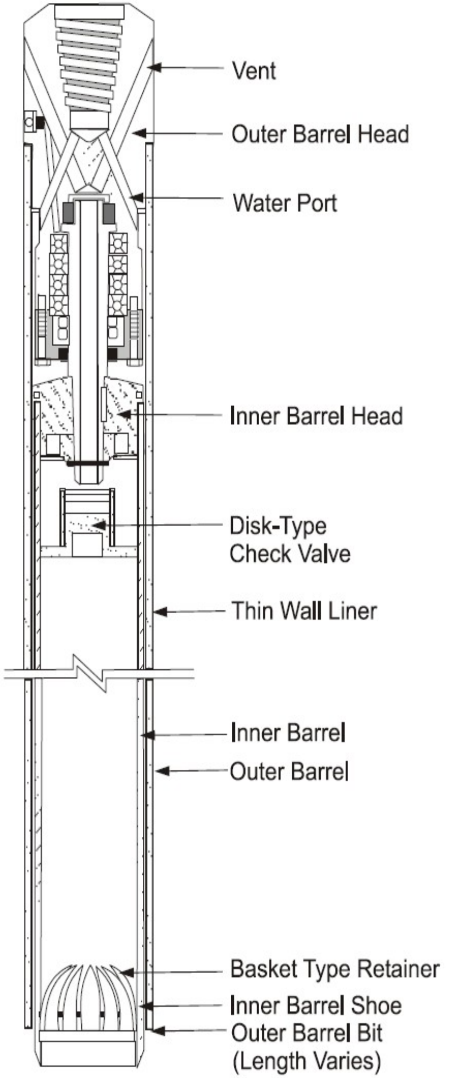


Figure 3-11. Denison sampler (FHWA, 1997).

Undisturbed Samplers

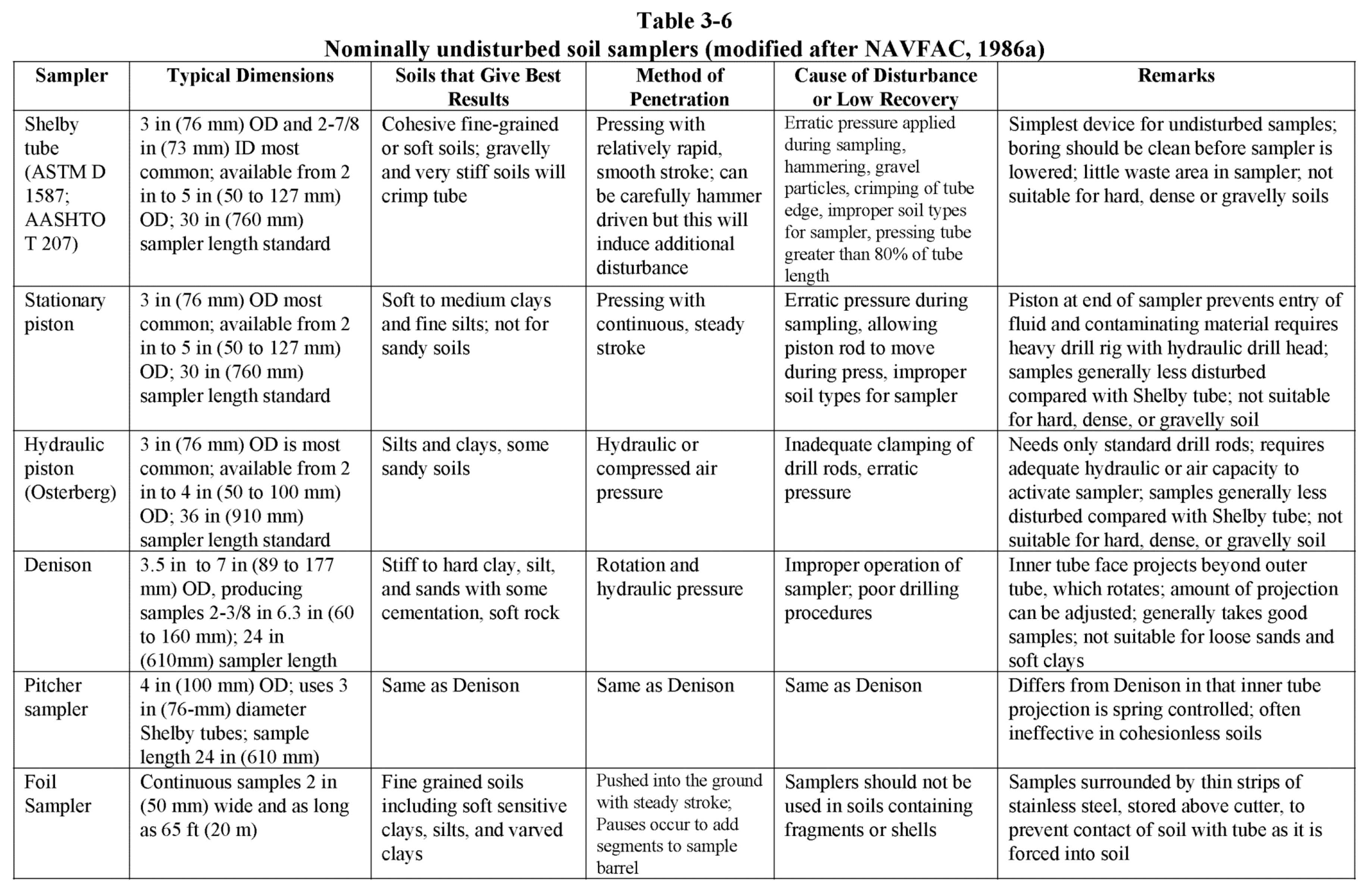


Table 3-6

Nominally undisturbed soil samplers (modified after NAVFAC, 1986a)

Sampler	Typical Dimensions	Soils that Give Best Results	Method of Penetration	Cause of Disturbance or Low Recovery	Remarks
Shelby tube (ASTM D 1587; AASHTO T 207)	3 in (76 mm) OD and 2-7/8 in (73 mm) ID most common; available from 2 in to 5 in (50 to 127 mm) OD; 30 in (760 mm) sampler length standard	Cohesive fine-grained or soft soils; gravelly and very stiff soils will crimp tube	Pressing with relatively rapid, smooth stroke; can be carefully hammer driven but this will induce additional disturbance	Erratic pressure applied during sampling, hammering, gravel particles, crimping of tube edge, improper soil types for sampler, pressing tube greater than 80% of tube length	Simplest device for undisturbed samples; boring should be clean before sampler is lowered; little waste area in sampler; not suitable for hard, dense or gravelly soils
Stationary piston	3 in (76 mm) OD most common; available from 2 in to 5 in (50 to 127 mm) OD; 30 in (760 mm) sampler length standard	Soft to medium clays and fine silts; not for sandy soils	Pressing with continuous, steady stroke	Erratic pressure during sampling, allowing piston rod to move during press, improper soil types for sampler	Piston at end of sampler prevents entry of fluid and contaminating material requires heavy drill rig with hydraulic drill head; samples generally less disturbed compared with Shelby tube; not suitable for hard, dense, or gravelly soil
Hydraulic piston (Osterberg)	3 in (76 mm) OD is most common; available from 2 in to 4 in (50 to 100 mm) OD; 36 in (910 mm) sampler length standard	Silts and clays, some sandy soils	Hydraulic or compressed air pressure	Inadequate clamping of drill rods, erratic pressure	Needs only standard drill rods; requires adequate hydraulic or air capacity to activate sampler; samples generally less disturbed compared with Shelby tube; not suitable for hard, dense, or gravelly soil
Denison	3.5 in to 7 in (89 to 177 mm) OD, producing samples 2-3/8 in 6.3 in (60 to 160 mm); 24 in (610mm) sampler length	Stiff to hard clay, silt, and sands with some cementation, soft rock	Rotation and hydraulic pressure	Improper operation of sampler; poor drilling procedures	Inner tube face projects beyond outer tube, which rotates; amount of projection can be adjusted; generally takes good samples; not suitable for loose sands and soft clays
Pitcher sampler	4 in (100 mm) OD; uses 3 in (76-mm) diameter Shelby tubes; sample length 24 in (610 mm)	Same as Denison	Same as Denison	Same as Denison	Differs from Denison in that inner tube projection is spring controlled; often ineffective in cohesionless soils
Foil Sampler	Continuous samples 2 in (50 mm) wide and as long as 65 ft (20 m)	Fine grained soils including soft sensitive clays, silts, and varved clays	Pushed into the ground with steady stroke; Pauses occur to add segments to sample barrel	Samplers should not be used in soils containing fragments or shells	Samples surrounded by thin strips of stainless steel, stored above cutter, to prevent contact of soil with tube as it is forced into soil

Other Exploratory Techniques

Table 3-4(c)
Other exploratory techniques (FHWA, 2002a)

Method	Procedure	Type of sample	Applications	Limitations / Remarks
Borehole camera	Inside of core hole viewed by circular photograph or scan	No sample, but a visual representation of the material	To examine stratification, fractures, and cavities in hole walls	Best above water table or when hole can be stabilized by clear water
Pits and Trenches	Pit or trench excavated to expose soils and rocks	Chunks cut from walls of trench; size not limited	To determine structure of complex formations; to obtain samples of thin critical seams such as failure surface	Moving excavation equipment to site, stabilizing excavation walls, and controlling groundwater may be difficult; useful in obtaining depth to shallow rock and for obtaining undisturbed samples on pit/trench sidewalls; pits need to be backfilled
Rotary or cable tool well drill	Toothed cutter rotated or chisel bit pounded and churned	Pulverized	To penetrate boulders, coarse gravel; to identify hardness from drilling rates	Identification of soils or rocks difficult
Percussive Method (jack hammer or air track)	Impact drill used; cuttings removed by compressed air	Rock dust	To locate rock, soft seams, or cavities in sound rock	Drill becomes plugged by wet soil

Spacing of Soil Borings

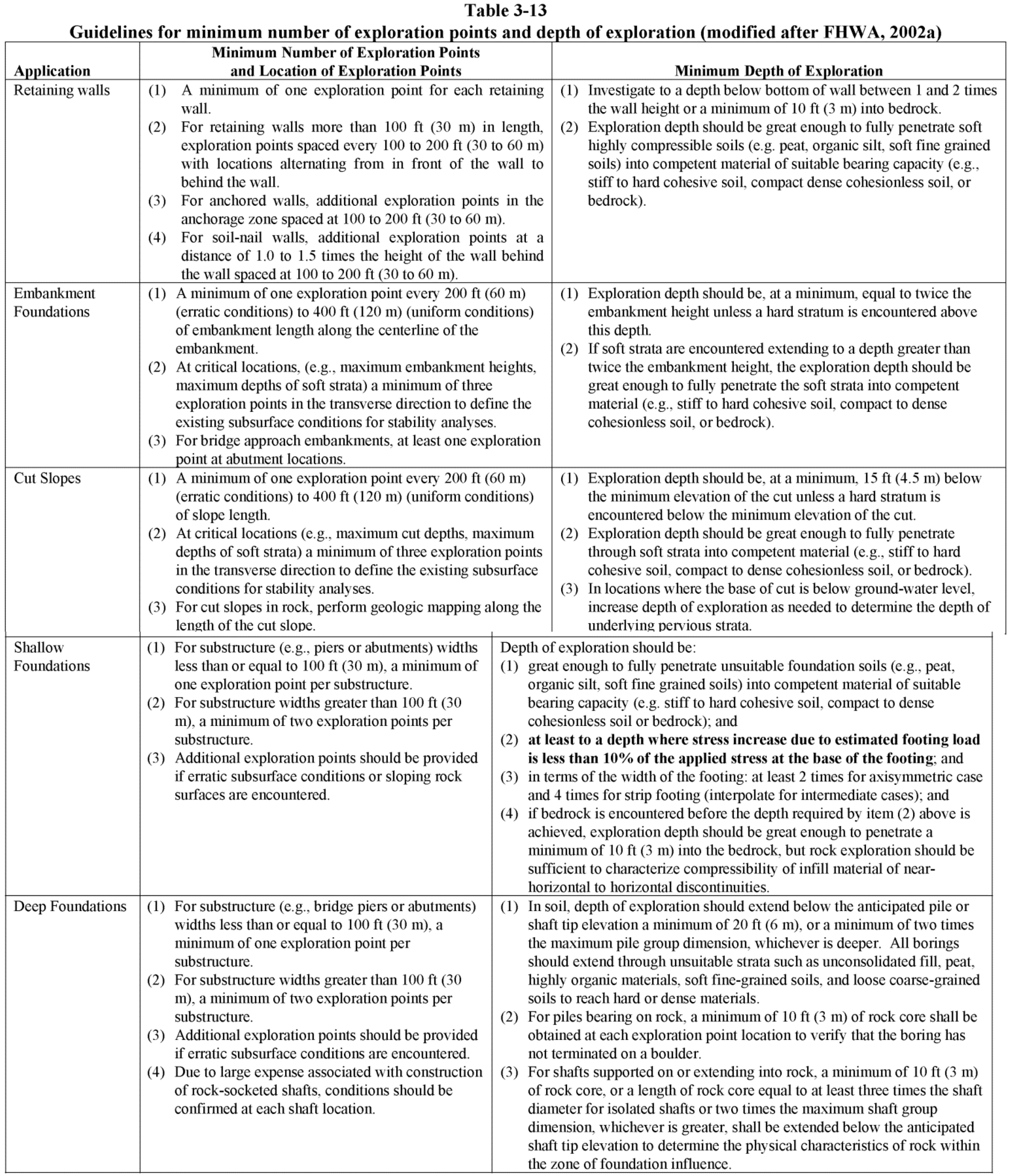


Table 3-13

Guidelines for minimum number of exploration points and depth of exploration (modified after FHWA, 2002a)

Application	**Minimum Number of Exploration Points and Location of Exploration Points**	**Minimum Depth of Exploration**
Retaining walls	(1) A minimum of one exploration point for each retaining wall. (2) For retaining walls more than 100 ft (30 m) in length, exploration points spaced every 100 to 200 ft (30 to 60 m) with locations alternating from in front of the wall to behind the wall. (3) For anchored walls, additional exploration points in the anchorage zone spaced at 100 to 200 ft (30 to 60 m). (4) For soil-nail walls, additional exploration points at a distance of 1.0 to 1.5 times the height of the wall behind the wall spaced at 100 to 200 ft (30 to 60 m).	(1) Investigate to a depth below bottom of wall between 1 and 2 times the wall height or a minimum of 10 ft (3 m) into bedrock. (2) Exploration depth should be great enough to fully penetrate soft highly compressible soils (e.g. peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g., stiff to hard cohesive soil, compact dense cohesionless soil, or bedrock).
Embankment Foundations	(1) A minimum of one exploration point every 200 ft (60 m) (erratic conditions) to 400 ft (120 m) (uniform conditions) of embankment length along the centerline of the embankment. (2) At critical locations, (e.g., maximum embankment heights, maximum depths of soft strata) a minimum of three exploration points in the transverse direction to define the existing subsurface conditions for stability analyses. (3) For bridge approach embankments, at least one exploration point at abutment locations.	(1) Exploration depth should be, at a minimum, equal to twice the embankment height unless a hard stratum is encountered above this depth. (2) If soft strata are encountered extending to a depth greater than twice the embankment height, the exploration depth should be great enough to fully penetrate the soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock).
Cut Slopes	(1) A minimum of one exploration point every 200 ft (60 m) (erratic conditions) to 400 ft (120 m) (uniform conditions) of slope length. (2) At critical locations (e.g., maximum cut depths, maximum depths of soft strata) a minimum of three exploration points in the transverse direction to define the existing subsurface conditions for stability analyses. (3) For cut slopes in rock, perform geologic mapping along the length of the cut slope.	(1) Exploration depth should be, at a minimum, 15 ft (4.5 m) below the minimum elevation of the cut unless a hard stratum is encountered below the minimum elevation of the cut. (2) Exploration depth should be great enough to fully penetrate through soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock). (3) In locations where the base of cut is below ground-water level, increase depth of exploration as needed to determine the depth of underlying pervious strata.
Shallow Foundations	(1) For substructure (e.g., piers or abutments) widths less than or equal to 100 ft (30 m), a minimum of one exploration point per substructure. (2) For substructure widths greater than 100 ft (30 m), a minimum of two exploration points per substructure. (3) Additional exploration points should be provided if erratic subsurface conditions or sloping rock surfaces are encountered.	Depth of exploration should be: (1) great enough to fully penetrate unsuitable foundation soils (e.g., peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g. stiff to hard cohesive soil, compact to dense cohesionless soil or bedrock); and (2) **at least to a depth where stress increase due to estimated footing load is less than 10% of the applied stress at the base of the footing**; and (3) in terms of the width of the footing: at least 2 times for axisymmetric case and 4 times for strip footing (interpolate for intermediate cases); and (4) if bedrock is encountered before the depth required by item (2) above is achieved, exploration depth should be great enough to penetrate a minimum of 10 ft (3 m) into the bedrock, but rock exploration should be sufficient to characterize compressibility of infill material of near-horizontal to horizontal discontinuities.
Deep Foundations	(1) For substructure (e.g., bridge piers or abutments) widths less than or equal to 100 ft (30 m), a minimum of one exploration point per substructure. (2) For substructure widths greater than 100 ft (30 m), a minimum of two exploration points per substructure. (3) Additional exploration points should be provided if erratic subsurface conditions are encountered. (4) Due to large expense associated with construction of rock-socketed shafts, conditions should be confirmed at each shaft location.	(1) In soil, depth of exploration should extend below the anticipated pile or shaft tip elevation a minimum of 20 ft (6 m), or a minimum of two times the maximum pile group dimension, whichever is deeper. All borings should extend through unsuitable strata such as unconsolidated fill, peat, highly organic materials, soft fine-grained soils, and loose coarse-grained soils to reach hard or dense materials. (2) For piles bearing on rock, a minimum of 10 ft (3 m) of rock core shall be obtained at each exploration point location to verify that the boring has not terminated on a boulder. (3) For shafts supported on or extending into rock, a minimum of 10 ft (3 m) of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.

Boring Location Plan and Interpreted Subsurface Profile

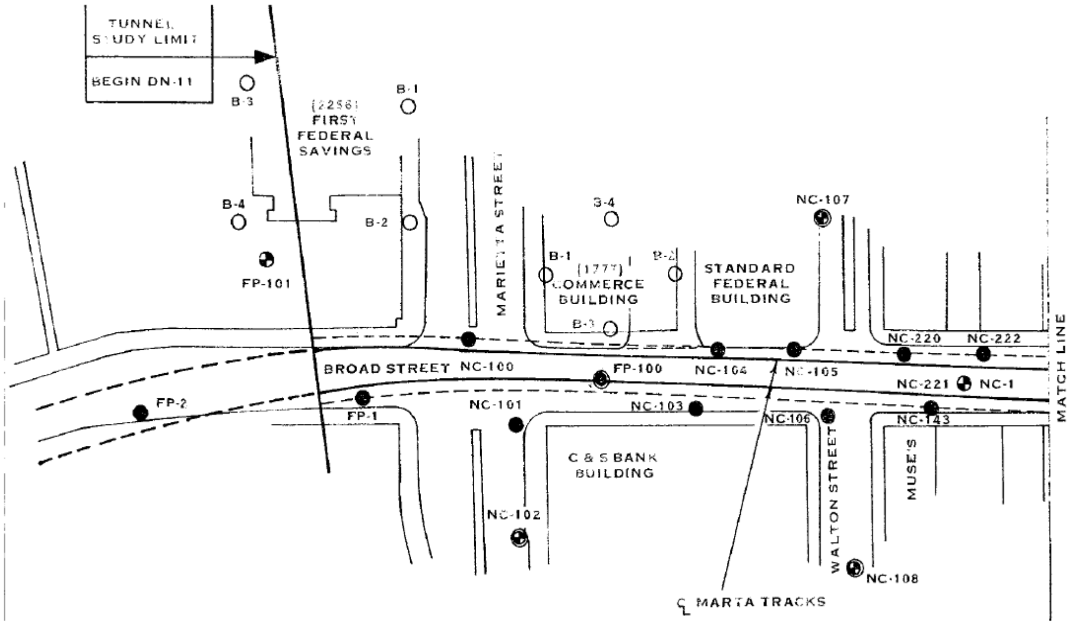


Figure 45. Boring location plan

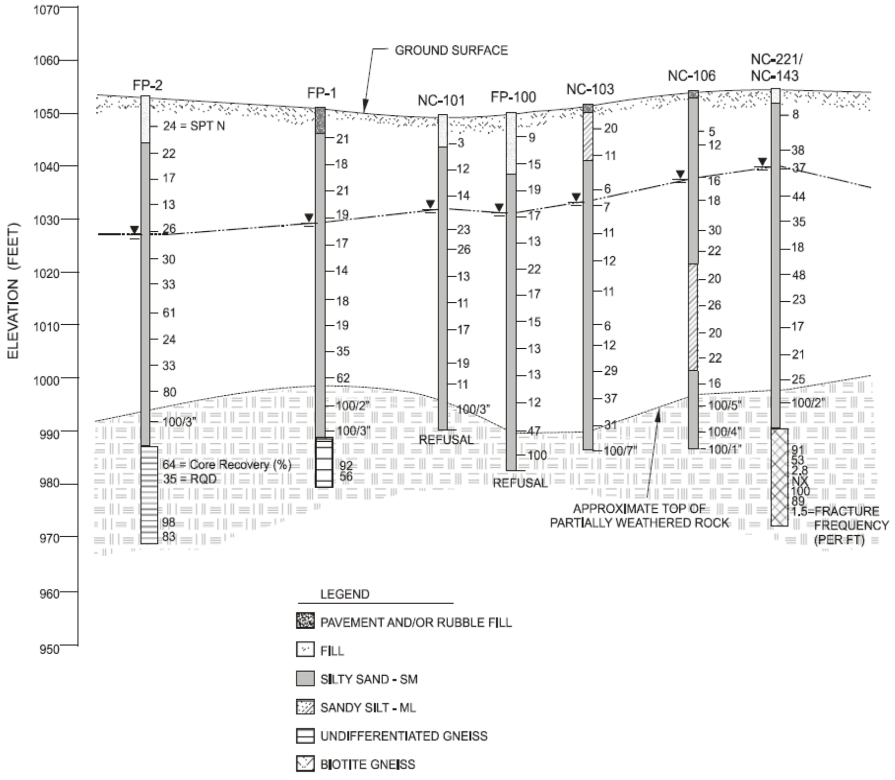


Figure 46. Interpreted subsurface profile.

Questions?