Training Course on Civil/Structural Codes and Inspection

BMA Engineering, Inc.

Overall Outline

3000. Site Investigation

- Objective and Scope
  - Present and discuss
    - Site investigation for foundations of nuclear power plants
    - Laboratory investigations and soil sampling of soils and rocks for engineering analysis and design of nuclear power plants

3000. Site Investigation

3100
- Site Investigation for Foundations of Nuclear Power Plants

3200
- Laboratory Investigations and Soil Sampling of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

3100. Site Investigation for Foundations of Nuclear Power Plants

- Site investigation for foundations of nuclear power plants is based on Regulatory Guide 1.132 [Revision 2 October 2003]
- Purpose
  – To describe methods for conducting field investigations to acquire the needed geotechnical data for defining subsurface conditions and identifying potential geologic hazards at the site in order to design nuclear power plant foundations for safety and performance

3100. Site Investigation for Foundations of Nuclear Power Plants

- Types of Data to be Acquired
- Literature Search and Reconnaissance
- Detailed Site Investigation
- Groundwater Investigations
- Construction Mapping
- Support Functions

3100. Site Investigation for Foundations of Nuclear Power Plants

- Types of Data to be Acquired
  – Geological Conditions
  – Engineering Properties of Soils and Rocks
  – Groundwater Conditions
  – Man-Induced Conditions
  – Cultural and Environmental
  – Related Considerations

3100. Site Investigation for Foundations of Nuclear Power Plants

- Types of Data to be Acquired

1. Geological Conditions

- Types and structure of soils and rocks at the surface and in the subsurface
- Degree and extent of weathering
- Petrological characteristics (structure, texture, and composition)
- Potential hazards (faulting, landslides, erosion, deposition)
- Caverns formed by dissolution or mining activity
- Ground subsidence
- Soil shrinking, swelling, and liquefaction potential
- Characteristics and orientation of bedding, foliations, or jointing

3I00. Site Investigation for Foundations of Nuclear Power Plants

- Types of Data to be Acquired

2. Engineering Properties of Soils and Rocks

- Density and seismic velocities
- Parameters of strength, elasticity, and plasticity
- Details are covered in Section 3200 [RG 1.138]

3. Groundwater Conditions

- Groundwater conditions at the site that include:
  - Groundwater levels
  - Thickness of aquifers and confining beds
  - Groundwater flow patterns
  - Transmissivities and storage coefficients

3I00. Site Investigation for Foundations of Nuclear Power Plants

- Types of Data to be Acquired

4. Man-Induced Conditions

- Existing construction and infrastructure in the site
- Dams or reservoirs whose locations may cause a flooding hazard or produce loading effects at the site
- Mining or oil and gas production and other fluid extraction or injection
- Presence of former industrial sites, underground storage tanks, or landfills
- potential for hazardous, toxic, or radioactive waste

3I00. Site Investigation for Foundations of Nuclear Power Plants

- Types of Data to be Acquired

5. Cultural and Environmental Considerations

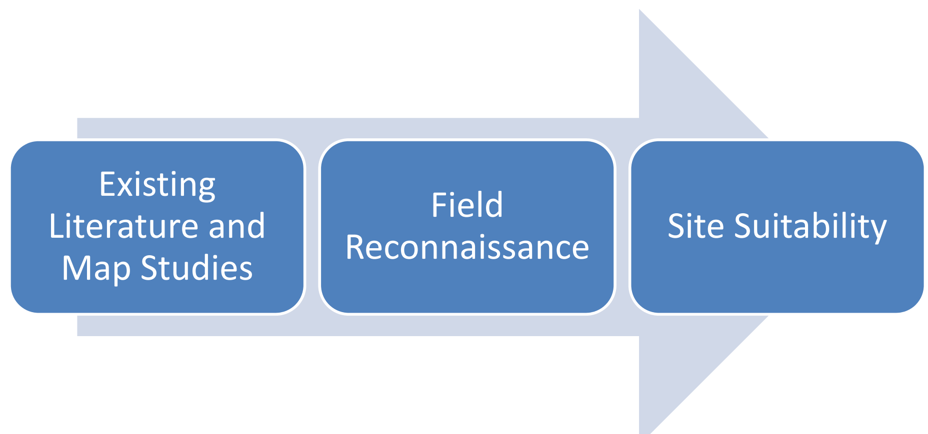
- Compliance with Archaeological Resources Protection Act of 1979 and the Native American Graves Protection and Repatriation Act of 1990
- Compliance with Clean Water Act (33 U.S.C. 1344)

6. Related Considerations

- Guidance on seismicity and related seismic data and historical records in Regulatory Guide 1.165
- Guidance on vibratory ground motion resulting from earthquakes

3I00. Site Investigation for Foundations of Nuclear Power Plants

- Literature Search and Reconnaissance



3I00. Site Investigation for Foundations of Nuclear Power Plants

- Literature Search and Reconnaissance

1. Existing Literature and Map Studies

- Acquire existing knowledge of geological and other site conditions
- Understanding of the regional geology
- Published material and existing maps of topography, geology, hydrology, and soils
- Studying aerial photographs and other remote sensing imagery
- Regional strain rates of Global Positioning System (GPS), if available
- Plans held by utilities should be consulted to locate services such as water, gas, electric, communication lines, power lines, access routes
- Records on mining, oil, gas, and water wells, and oil exploration
- Records on cultural resources

3I00. Site Investigation for Foundations of Nuclear Power Plants

- Literature Search and Reconnaissance

2. Field Reconnaissance

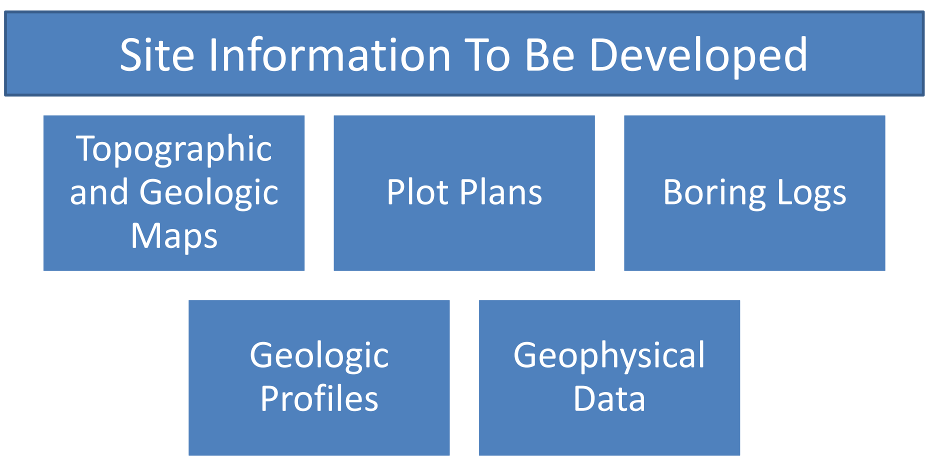
- Perform a preliminary field reconnaissance of the site and its surrounding area using an appropriate topographic or geologic map for
  - special geologic features and conditions such as landslides, faults and past seismic activity
  - potential borrow areas, quarry sites, or water impoundment areas

3. Site Suitability

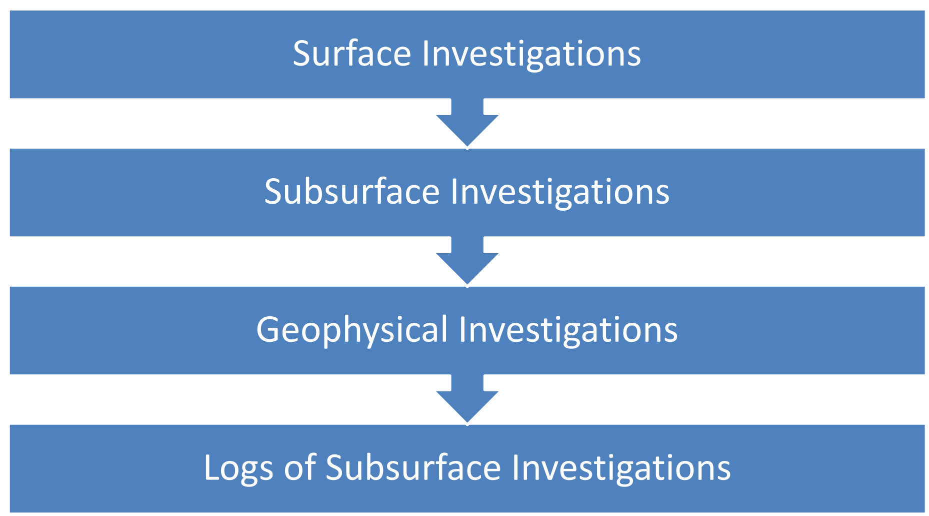
- Make a preliminary determination of site suitability and formulate a plan for detailed site investigations

3I00. Site Investigation for Foundations of Nuclear Power Plants

Detailed Site Investigations



Detailed Site Investigations



Detailed Site Investigations
Surface Investigations

- Surface Investigations
  - Conducting detailed surface geological and geotechnical engineering investigations over the site area to assess all relevant soil and rock characteristics
  - Preparing topographic maps at suitable scales to
    - Plot geologic, structural, and engineering details at the site and
    - Note related conditions in surrounding areas (borrow areas, quarries, or access roads)

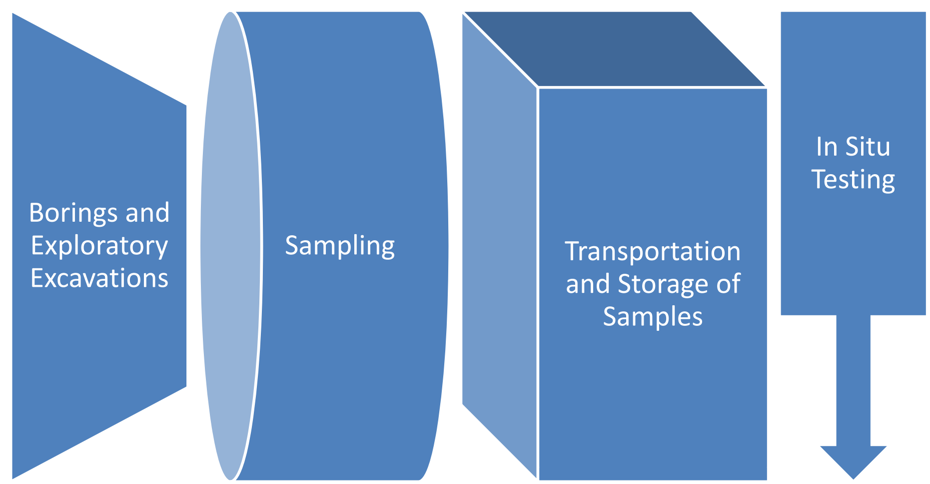
Detailed Site Investigations
Surface Investigations

- Surface Investigations (Cont…)
  - Features to be identified on the Map
    - Hydrogeologic, and surface geologic features
    - Rock outcrops, soil conditions, evidence of past landslides or soil liquefaction, faults, fracture patterns, geologic contacts, and lineaments
    - Local engineering geology and soil conditions
    - Surface-water features (rivers, streams, or lakes, surface drainage channels, ponds, springs)

Detailed Site Investigations
Subsurface Investigations

- Objectives of Subsurface Investigations
  - To expand the knowledge of the three-dimensional distribution of both geologic conditions (soils, rocks, structure) and engineering properties at the site and at borrow areas
  - To gain further information on possible safety hazards such as underground cavities, hidden faults, or contacts

Subsurface Investigations



Detailed Site Investigations
Subsurface Investigations

- Borings and Exploratory Excavations
  - Boreholes are effective means of obtaining detailed information on geologic formations (identifying and classifying soil types, Obtaining groundwater data) in the subsurface and their engineering properties beneath planned foundations
  - Excavations in the form of test pits, trenches, and exploratory shafts may be used to complement the borehole exploration

Detailed Site Investigations
Subsurface Investigations

Methods of Borings and Exploratory Excavations

- Pits, trenches, shafts, tunnels
- Auger boring
- Hollow stem auger boring
- Wash boring
- Rotary drilling
- Percussion drilling
- Cable drilling
- Continuous sampling or displacement Boring

- Procedure, applicability and limitations are available in Appendix C of RG 1.132

Detailed Site Investigations
Subsurface Investigations

- Examples of Common Methods for Borings

Auger Borings

- Provide disturbed samples suitable for determining soil type, Atterberg limits, and Proctor compaction testing
- Most useful for preliminary soil type investigations, advancing holes for other sampling methods, determining depth to top of bedrock, and installing

Wash Borings

- Combination of water circulation and a loosening of the soils using various types of bits
- Preferred method for obtaining good quality samples or obtaining reliable measurements of penetration resistance

Detailed Site Investigations
Subsurface Investigations

- Borings and Exploratory Excavations
  - Each safety-related structure should have at least one continuously sampled boring
  - Spacing and depth of borings for a site of safety-related structures should be chosen according to the complexity of subsurface conditions and foundation requirements
  - Appendix D of RG 1.132 provides guidelines on spacing of borings and minimum depth of penetration for different structures

Detailed Site Investigations

Subsurface Investigations

- Spacing For Boring of Safety-related Foundations
  - At least one boring should be at the location of every safety-related structure
  - Where variable conditions are found, spacing should be smaller
  - Where cavities or other discontinuities may occur, spacing should be small enough to detect such features

Detailed Site Investigations

Subsurface Investigations

- Depth of Penetration For Boring of Safety-related Foundations
  - Should extend at least 10 m (33 ft) below the lowest part of the foundation
  - If competent rock is encountered at lesser depths than , borings should penetrate to the greatest depth where discontinuities or zones of weakness or alteration can affect foundations and should penetrate or at least 6 m (20 ft) into sound rock

Detailed Site Investigations

Subsurface Investigations

- Depth of Penetration For Boring of Safety-related Foundations
  - Depth should be sufficient to define the site geology and to sample all materials that may swell, consolidate, be unstable under earthquake loading, or whose physical properties would affect foundation behavior or stability
  - Maximum depth (where soils are very thick) should be where vertical stress change is less than 10% of the effective in situ overburden stress

Detailed Site Investigations

Subsurface Investigations

- Boring Spacing and Depth of Penetration

Buildings, Retaining Walls, Concrete Dams

- Spacing
  - At least one boring beneath every safety-related structure
  - at least one boring per 900 m2 (10,000 ft2)
  - One boring per 30 m (100 ft) for essentially linear structures
  - A number of borings along the periphery and at corners
- Minimum Depth of Penetration
  - At least one-fourth of the borings and a minimum of one boring per structure to penetrate into sound rock or to maximum depth
  - Others to a depth below foundation elevation equal to the width of structure or to a depth equal to the foundation depth below the original ground surface, whichever is greater

Detailed Site Investigations

Subsurface Investigations

- Boring Spacing and Depth of Penetration

Earth Dams, Dikes, Levees, Embankments

- Spacing
  - One per 30 m (100 ft) along axis of structure and at critical locations perpendicular to the axis to establish geological sections with groundwater conditions for analysis
- Minimum Depth of Penetration
  - One per 60 m (200 ft) to maximum depth
  - Others should penetrate all strata whose properties would affect the performance of the foundation

Detailed Site Investigations

Subsurface Investigations

- Boring Spacing and Depth of Penetration

Deep Cuts, Canals

- Spacing
  - One per 30 m (100 ft) along axis of structure and at critical locations perpendicular to the axis to establish geological sections with groundwater conditions for analysis
- Minimum Depth of Penetration
  - One per 60 m (200 ft) to sound rock or to maximum depth
  - Others to cut depth or to below the lowest slope failure zone
  - Penetrate previous strata below which groundwater may influence stability

Detailed Site Investigations

Subsurface Investigations

- Boring Spacing and Depth of Penetration

Pipelines

- Spacing
  - One per 30 m (100 ft) for buried pipelines
  - At least one boring for each footing for pipelines above ground
- Minimum Depth of Penetration
  - For buried pipelines, one of every three to penetrate sound rock or to maximum depth
  - Others to 5 times pipe diameters below the elevation
  - For pipelines above ground, depths as for foundation structures

Detailed Site Investigations

Subsurface Investigations

- Boring Spacing and Depth of Penetration

Tunnels

- Spacing
  - One per 30 m (100 ft)
  - May vary for rock tunnels, depending on rock type
- Minimum Depth of Penetration
  - One per 60 m (200 ft) to penetrate sound rock or to maximum depth
  - Others to 5 times the tunnel diameters below the elevation

Detailed Site Investigations

Subsurface Investigations

- Boring Spacing and Depth of Penetration

Reservoirs, Impoundments

- Spacing
  - As per dams or dikes
  - Spacing varies with largest concentration near control structures coverage decreasing with distance
- Minimum Depth of Penetration
  - At least one-fourth to penetrate that portion of the saturation zone that may influence seepage conditions or stability
  - Others to a depth of 7.5 m (25 ft) below reservoir

Detailed Site Investigations

Subsurface Investigations

- Borings and Exploratory Excavations
  - The borehole should be protected by drilling mud or casing and the top of the hole should be protected by a suitable surface casing as needed
  - After use, each borehole should be grouted to prevent vertical movement of groundwater through the borehole
  - Borehole elevation should be measured to the nearest 3 cm (0.1 ft) and correlated to the elevation datum used for the site

Detailed Site Investigations

Subsurface Investigations

- Borings and Exploratory Excavations
  - Field inspector duties during drilling
    - Observing and describing drilling tools and procedures, geologic materials and their discontinuities, and drilling activities and groundwater measurements
    - Selecting and preserving samples and performing field tests on core samples
    - Photographing site conditions and cores
    - Completing the drilling log and/or entering information into a cataloging system
    - Recording information and data from in-situ tests.

Detailed Site Investigations

Subsurface Investigations

- Sampling
  - Sampling of soils in boreholes should include, as a minimum, the recovery of samples at regular intervals and at changes in materials
  - Alternating split spoon and undisturbed samples with depth is recommended
  - Color photographs of all cores should be taken soon after removal from the borehole to document the condition of the soils at the time of drilling

Detailed Site Investigations
Subsurface Investigations

Methods of Sampling Soil or Rock

Hand cut or cylindrical sample	Fixed-piston Sampler	Hydraulic piston sampler (Osterberg Sampler)	Free-piston Sampler	Open drive Sampler
Swedish Foil Sampler	Split-barrel or splitspoon sampler	Auger sampling	Rotary core barrel	Denison sampler
Shot core boring (Calyx)	Oriented integral sampling	Wash sampling or cuttings sampling	Submersible vibratory (Vibracore) sampler	Underwater piston corer
Gravity corer				

- Procedure, applicability and limitations are available in Appendix C of RG 1.132

Detailed Site Investigations
Subsurface Investigations

- Sampling

Sampling Rock

- Core samples are needed to observe and define rock composition, structure, bedding, jointing, fracturing, and weathering
- Rocks should be sampled to a depth below which rock characteristics do not influence foundation performance
- The nature, geometry, and spacing of any discontinuities or anomalous zones should be determined by means of suitable logging or in situ observation methods

Detailed Site Investigations
Subsurface Investigations

- Sampling

Sampling Coarse-Grained Soils

– Samples should be obtained when changes in materials occur and at regular intervals in depth of
  - 1.5 m (5 ft) until a depth of 15 m (50 ft) below foundation level
  - 3 m (10 ft) beyond 15 m (50 ft) below foundation level

– One or more borings for each major structure should be continuously sampled

Detailed Site Investigations
Subsurface Investigations

- Sampling

Sampling Coarse-Grained Soils

– Split spoon sampling and standard penetration tests should be used to define the soil profile and variations of soil conditions

– When coarse-grained soils contain gravels and boulders, excavations like trenches or pits into the zones of interest may be required and percentage of boulders should be estimated

Detailed Site Investigations

Subsurface Investigations

- Sampling

Sampling Moderately Compressible or Normally Consolidated Clay or Clayey Soils

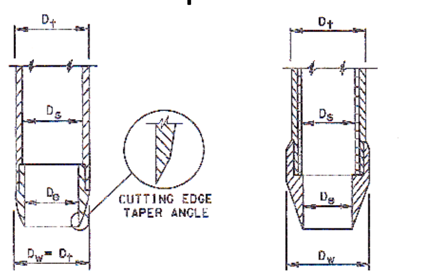
- – Undisturbed samples should be obtained and continuous throughout the compressible strata in one or more principal borings for each major structure
- – Borings used for undisturbed sampling of soils should be at least 7.6 cm (3 in.) in diameter

Soil Sampling

- Principles, equipments, procedures, and limitations for obtaining, handling, and preserving soil samples
- Disturbed samples are primarily used for moisture content, Atterberg limits, specific gravity, sieve analysis or grain-size distribution, and compaction characteristics
- Undisturbed samples are useful for strength, compressibility, and permeability tests

Soil Sampling

- Parameters that may affect sample disturbance during sampling
  - – Area ratio C_a
  - – frictionInside clear ratio C_i
  - – Outside clearance ratio C_o



$$C_i = \frac{D_s - D_e}{D_e}$$

$$C_o = \frac{D_w - D_t}{D_t}$$

$$C_a = \frac{D_w^2 - D_e^2}{D_e^2}$$

Soil Sampling

- Parameters that may affect sample disturbance during sampling (Cont …)
  - – Length-to-diameter ratio: should be 5-10 for cohesionless soils and 10-20 for cohesive soils
  - – Method of advancing the sample tube
  - – Stress relief (water, drilling mud, casing)
  - – Sample recovery

Soil Sampling

- Disturbance after sampling may be due to:
  - change of water content,
  - moisture migration within sample,
  - Penetration of voids by wax used to seal sample
  - vibration due to sample transportation,
  - freezing of silt or clay samples,
  - chemical reaction between sample and tube,
  - disturbance due to extruding sample from tube

Soil Sampling

- Selection of sampling apparatus to obtain undisturbed samples
  - Two basic types of sampling apparatus: push-tube samplers and rotary core-barrel samplers

TABLE 2-3. Guide for Selecting Sampler for Obtaining High-Quality Undisturbed Samples

Soil Type	Suggested Sampler Type or Method
Very soft cohesive soils Organic soils Varved clays	Stockinette sampler, foil sampler, or fixed-piston sampler
Soft-to-medium cohesive soils	Fixed-piston sampler
Fine-to-medium sands above the water table	Hand trimming by using the cylinder with advanced trimming technique Fixed-piston sampler in a cased and/or mudded borehole
Fine-to-medium sands below the water table	In situ freezing and coring Fixed-piston sampler in a mudded borehole
Alternating layers of soil and rock Hard or dense cohesive soils Rock	Rotary core-barrel sampler

Soil Sampling

- Push-tube samplers include
  - open-tube samplers and
  - piston samplers (free-, fixed-, and retractable-piston samplers)
- Rotary core-barrel samplers include
  - single-tube core-barrel samplers,
  - double-tube core-barrel samplers, and
  - triple-tube core-barrel samplers

Soil Sampling

- Sampling apparatus to obtain undisturbed samples
  - Undisturbed samples of medium to fine sands can be obtained by hand trimming or in situ freezing and core drilling
  - Fixed-piston samplers in a mudded borehole can be used for sand below the water table
  - The sample diameter should exceed six times the size of the largest particle size

Drill Rigs and Appurtenant

- Drill rigs elements
  - Power source
  - Fluid pump and accessories
  - Drill head
  - Hoists
  - Derrick
  - Mounting platform
  - Ancillary equipment

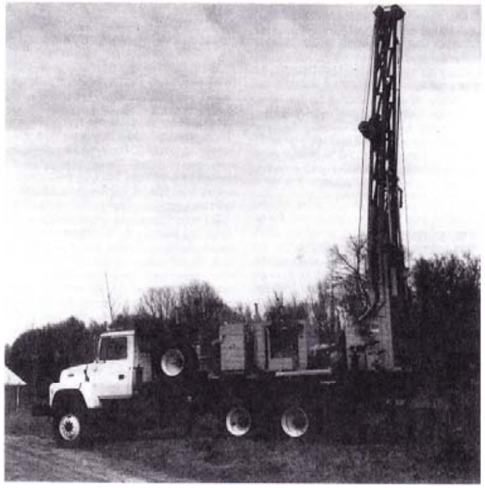


FIGURE 3-1. Truck-Mounted Rotary Drill Rig with a Hydraulic Drive System

Drill Rigs and Appurtenant

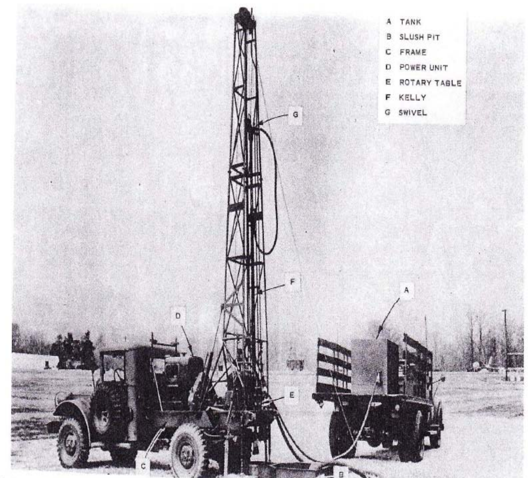


FIGURE 3-3. Truck-Mounted Rotary Drill Rig with a Chain-Feed Drive System

FIGURE 3-2. Truck-Mounted Rotary Drill Rig with Specific Features of the Drill Rig Identified

Drill Rigs and Appurtenant

- Types of drills
  - Drills for wash borings
    - Include chopping, jetting and washing
  - Chunk drills
    - Up-and-down hammering

Drill Rigs and Appurtenant

- Types of drills (cont..)
  - Rotary drills
    - Rotary action coupled with downward pressure plus cleaning action of drilling fluid
    - Used for drilling, sampling, bucket-auger drilling, and reverse-circulation drilling
    - Truck mounted: can drill 200 to 1000 ft
    - Hydraulic mounted: can drill 500 to 2500 ft

Drill Rigs and Appurtenant

- Types of drills (cont..)
  - Hammer drills
    - Either driving or rotating and driving a drill
    - Borehole diameter range from 4 to 16 inches
    - Becker hammer drill: used in sand, gravel , and boulders
    - Becker CRS drill: drill is hammered and rotated
    - Electric reamer system: rotation plus percussion
  - Auger drills
    - Rotary drilling with other types of augers

Drill Rigs and Appurtenant

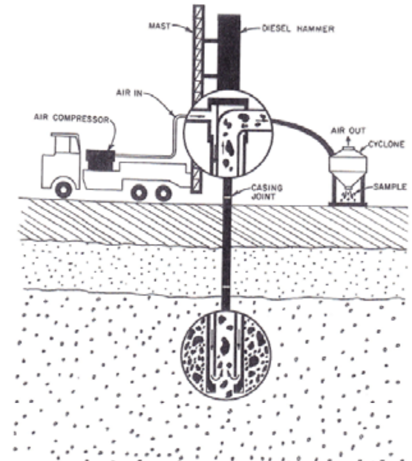
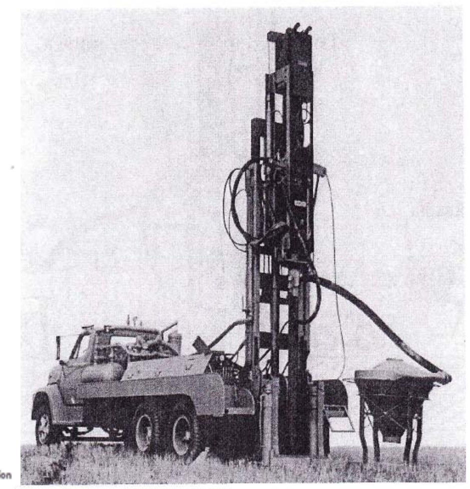
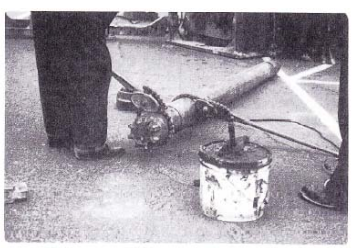


FIGURE 3-5. Schematic of Becker Hammer Drilling and/or Sampling Operations Using Reverse Air Circulation (Harder 1993)



Becker Hammer Drill

Drill Rigs and Appurtenant



A Plugged Bit That Is Used to Obtain Becker Penetration Resistance (Harder 1993)

Several Open-Type Becker Bits (Harder 1993)

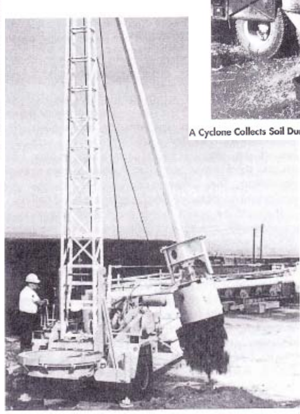
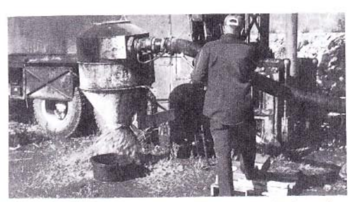


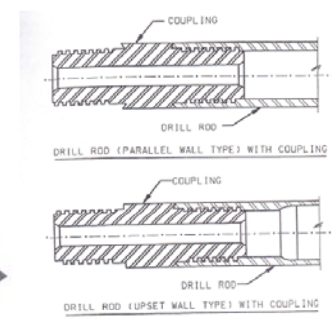
FIGURE 3-10. A Bucket-Auger Drill in Operation



A Cyclone Collects Soil During Becker Hammer Drilling Operations (Harder 1993)

Drill Rigs and Appurtenant

- Accessories and appurtenant equipment
  - Standard nomenclature
  - Drill rods
  - Drill bits
  - Casing



Cross Sections of Drill Rods that Illustrate Upset and Parallel Wall Tubing (after Hvorslev 1949)

Typical Tri-Cone Bits

FIGURE 3-13. Several Rotary Bits

Several Drag Bits

. Several Chopping Bits

Drill Rigs and Appurtenant

- Accessories and appurtenant equipment (Cont…)
  - Portable sumps
  - Surface casing
  - Augers
  - Bailers and sand pumps
  - Fishing tools
  - Miscellaneous hand tools

Standard Carbide Insert Bit and a Pyramid Carbide Bit

Typical Diamond Coring Bit

FIGURE 3-19. Holding Fork and a Hoisting Plug

Drilling Fluid

- Purpose:
  - cleaning and transporting the cutting
  - Cooling and lubricating the drill bit and rods
- Types of drilling fluid
  - Compressed air
  - Foam
  - Clear water
  - Water-based muds

Drilling Fluid

- Properties of water-based muds
  - Viscosity
  - Density
  - Gel strength
  - Filtration

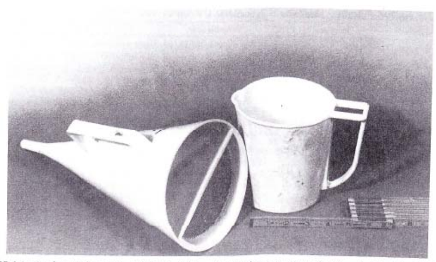


FIGURE 4-1. Marsh Funnel and a 1-qt (0.95-dm³) Measuring Cup for Determining the Viscosity of Drilling Mud

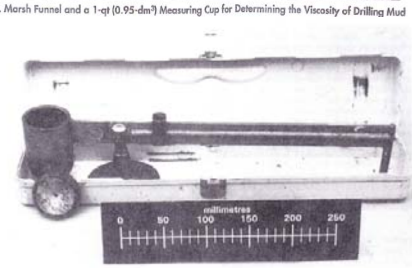


FIGURE 4-2. Mud Balance for Determining the Density of Drilling Mud

Drilling Fluid

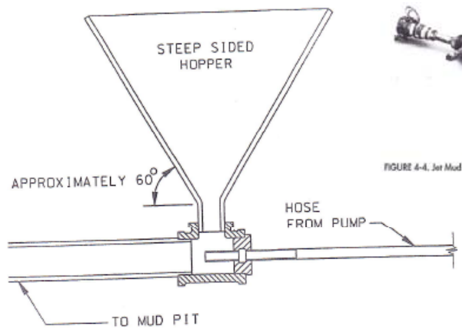
TABLE 4-1. Properties of Drilling Mud (after N. L. Baroid/N. L. Industries, Inc.)

Property	Influences	Desirable Limit	Control
Density (weight)	Drilling rate Hole stability	Less than about 1,080 kg/m³ (9.0 lb/gal) (mud balance)	Dilute with water or remove solids to decrease Add barium to increase
Viscosity	Cuttings transport Cuttings settlement Circulation pressures	34–40 sec/dm³ (32–38 sec/qt) (marsh funnel and measuring cup)	Add water, phosphates, or lignites to thin Add bentonite or polymers to thicken
Filtration	Wall cake thickness	Very thin (<0.2 cm [1/16 in.])	Control density and viscosity of mud Polymers
Sand content	Mud density Abrasion to equipment Drilling rate	Less than 2 percent by volume	Add water to lower viscosity Good mud pit design Use desander
pH (acidity or alkalinity)	Mud properties Filtration control Hole stability Corrosion of equipment	8.5 to 9.5 (neutral is 7.0)	Increase with sodium carbonate Decrease with sodium bicarbonate
Calcium content[a] (hard or soft water)	Mud properties Filtration control	Less than 100 parts per million (ppm) calcium	Pretreat mixing water with sodium bicarbonate

[a] For other salts, dilute salt content with fresh water or use organic polymers in the drilling fluid.

Drilling Fluid

- Mixing and handling
  - Affected by water quality and method of mixing



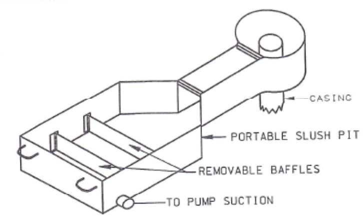
Steep-Sided Hopper Mud Mixer


FIGURE 4-4. Jet Mud Mixer

Drilling Fluid

- Drilling and sampling problems
  - Hole stabilization
    - Coving, squeezing ground
  - Control of hydrostatic pressure
  - Improved sample recovery
  - Enhanced pump capacity
  - Solids recirculation


FIGURE 4-7. Small Desanding Cone



Portable Mud Pit (Sketch)

Drilling Fluid

- Limitations and precautions
  - Hydraulic fracturing
    - In earth dam embankments when drill fluid is used in the fill
  - Formation permeability
  - Environmental drilling
  - Effect on strength testing
    - Should be carefully inspected for drilling mud infiltration

Detailed Site Investigations
Subsurface Investigations

- Undisturbed Samples
  - Undisturbed samples are obtained using one of two methods: push samplers and rotary samplers
  - These methods permit obtaining samples for shear strength, consolidation, permeability, and density tests
  - Example push samplers: Hvorslev fixed- position sampler and Osterberg hydraulic piston sampler
  - Example rotary samplers: Denison barrel and Pitcher Sampler

Detailed Site Investigations

Subsurface Investigations

- Undisturbed Samples
  - Rotary samplers are more disruptive to soil structure
  - Undisturbed samples can be sliced to permit detailed study of subsoil stratification
  - Can obtain undisturbed samples of clays and silts and nearly undisturbed samples of some sands
  - Care is necessary in transporting undisturbed samples (sands and silts disturbance of vibration)

Detailed Site Investigations

Subsurface Investigations

- Undisturbed Samples of Cohesionless Soil
  - To prevent handling disturbance in cohesionless soil, obtain 3 inch Shelby tube samples, drain them, and freeze them before transportation
  - Chemical stabilization or impregnation can be used as to sample and preserve the natural structure of cohesionless granular material
  - High quality block samples can be obtained by means of hand-carving oversized blocks of soil or hand-advancing of thin-walled tubes

Equipment for Undisturbed Soil Sampling in Borings

- Sampler types:
  - Push-tube thin-walled tube samplers (for soft to medium clays and fine sands)
    - Open samplers
    - Piston samplers
  - Rotary core-barrel samplers (for hard soil for smooth penetration)
    - Denison sampler
    - Pitcher sampler
    - WES modified Denison sampler

Equipment for Undisturbed Soil Sampling in Borings

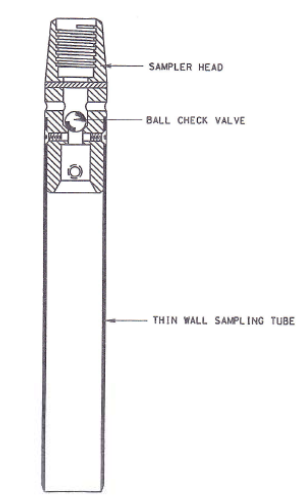


FIGURE 5-1. Open-Tube Sampler

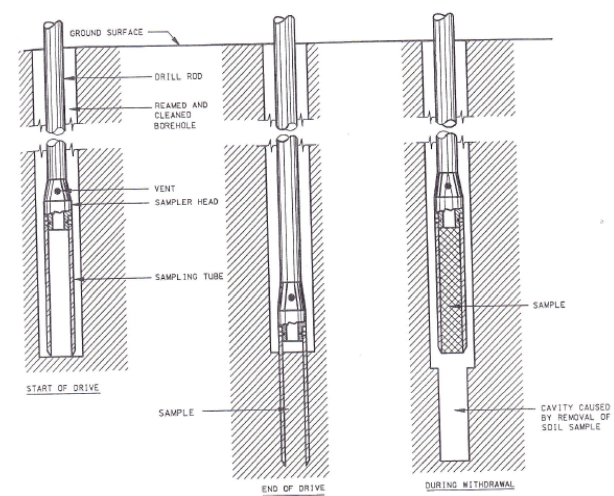
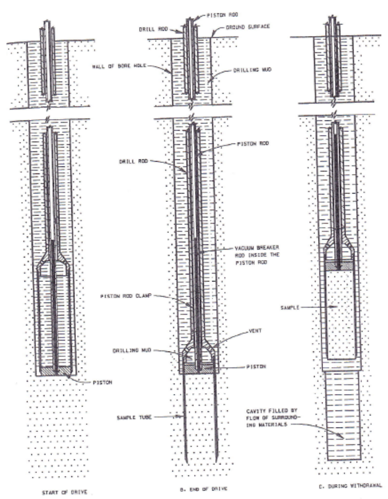


FIGURE 5-2. Sampling Operations Using the Open-Tube Sampler

Equipment for Undisturbed Soil Sampling in Borings



Operation of the Hvorslev Sampler

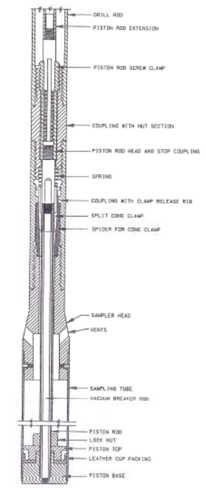


FIGURE 5-4. Cross-Sectional View of Hvorslev Fixed-Piston Sampler

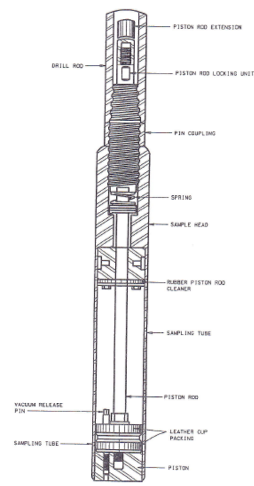


FIGURE 5-6. Cross-Sectional Diagram of Butters Sampler (after U.S. Department of the Interior, Bureau of Reclamation 1974)

Equipment for Undisturbed Soil Sampling in Borings

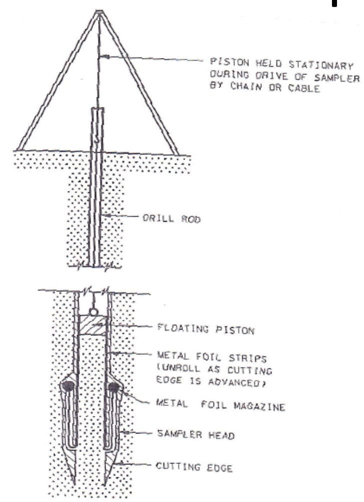


FIGURE 5-9. Swedish Foil Sampler

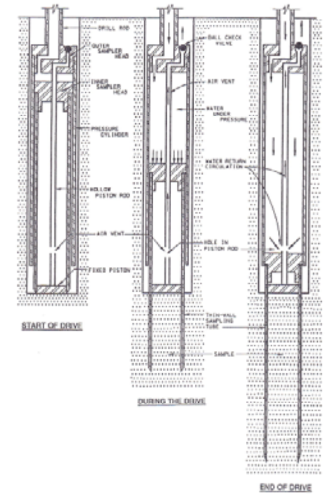


FIGURE 5-8. Cross-Sectional View of Osterberg Sampler, Illustrating Operation (after U.S. Department of the Interior, Bureau of Reclamation 1974)

Equipment for Undisturbed Soil Sampling in Borings

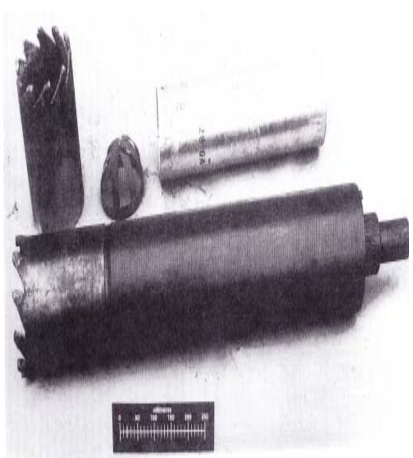


FIGURE 5-11. Denison Sampler

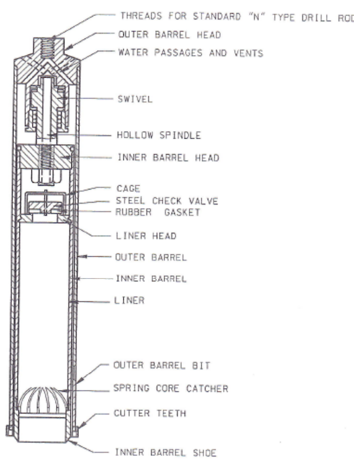


FIGURE 5-12. Denison Sampler (after Hvorslev 1949)

Equipment for Undisturbed Soil Sampling in Borings

- Other samplers
  - Hollow-stem auger sampler
  - Sand samplers

FIGURE 5-13. Pitcher Double-Tube Core-Barrel Sampler

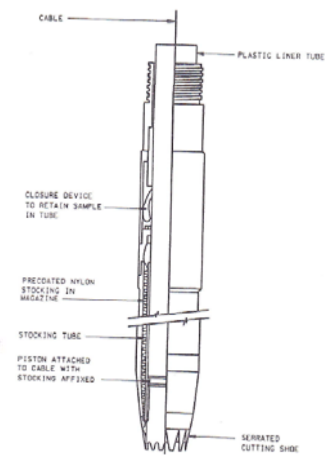


FIGURE 5-10. Delft Continuous Soil Sampler

Equipment for Undisturbed Soil Sampling in Borings

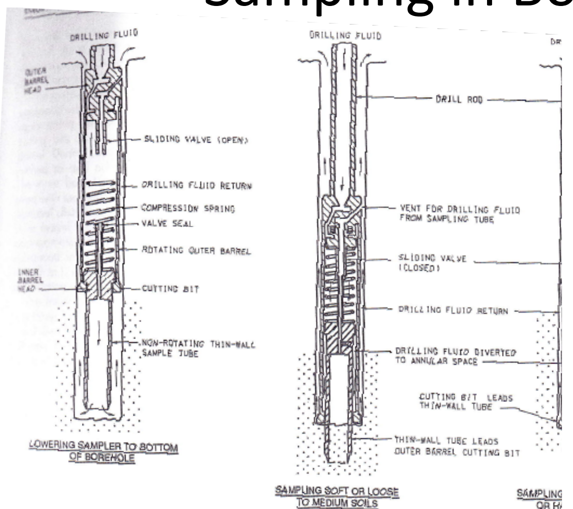
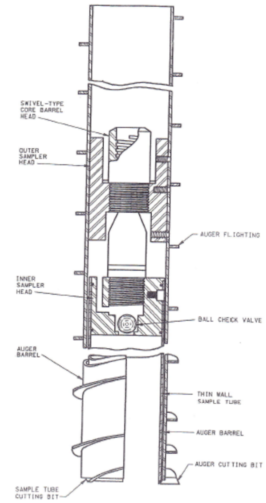


FIGURE 5-14. Operation of the Pitcher Sampler (after Winterkorn and Fang 1975)



Hollow-Stem Auger with Thin-Wall Sampling Tube (after U.S. Department of the Interior 1974)

Equipment for Undisturbed Soil Sampling in Borings

TABLE 5-1. Auger Sizes (Diameters) (after Acker 1974)

Hole Diameter		Auger Flighting (OD)		Auger Axle (ID)		Sampling Tools		Core Barrels
mm	in.	mm	in.	mm	in.	mm	in.	
159	6-1/4	127	5	57	2-1/4	51	2	AWG
171	6-3/4	146	5-3/4	70	2-3/4	64	2-1/2	BWG
184	7-1/4	159	6-1/4	83	3-1/4	76	3	NWG
337	13-1/4	305	12	152	6		Denison	102 × 140 mm (4 × 5-1/2 in.) core-barrel sampler

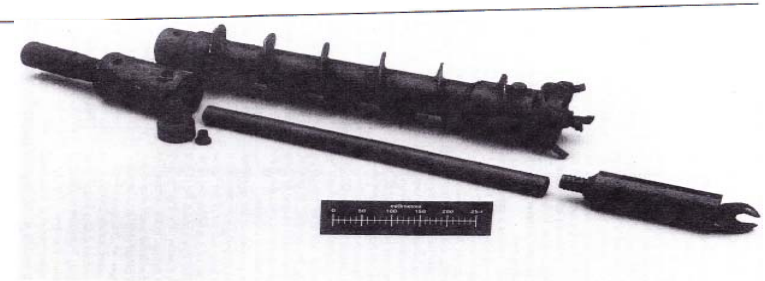


FIGURE 5-16. Hollow-Stem Auger with a Center Drag Bit

Equipment for Undisturbed Soil Sampling in Borings

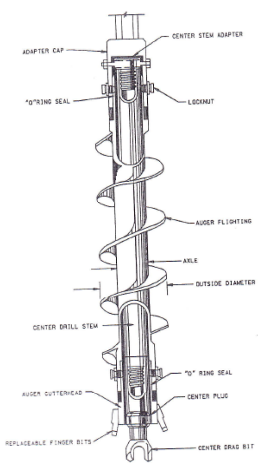


FIGURE 5-17. Isometric drawing of Hollow-Stem Auger with the Center Drag Bit, Which Can Be Used with Soil Sampling Devices (after Acker 1974)

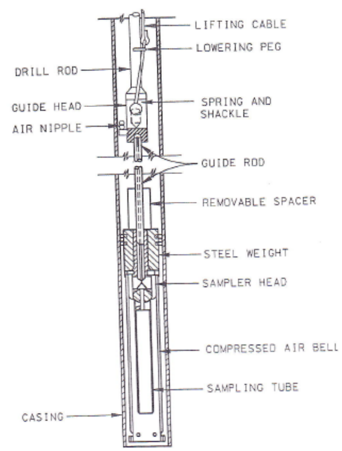


FIGURE 5-18. Bishop Sand Sampler (after Hvorslev 1949)

Equipment for Undisturbed Soil Sampling in Borings

- Sample tubes
  - Diameter
    - 5 inch for cohesive and 3 inch for cohesionless soils
  - Length (typically 3 ft)
  - Area ratio (12% for 5 inch and 10% for 3 inch tubes)
  - Cutting edge (smooth, sharp)
  - Material (clean tubing and coating)

Equipment for Undisturbed Soil Sampling in Borings

- Minimum sample diameter

TABLE 2-5. Minimum Sample Diameter or Dry Weight for Selected Laboratory Tests

Sample Type	Test	Minimum Sample Diameter[a]		Minimum Dry Weight[a]	
		cm	in.	kg	lb
Undisturbed	Unit weight	7.6	3.0	—	—
	Permeability	7.6	3.0	—	—
	Consolidation	12.7	5.0	—	—
	Triaxial compression	12.7	5.0[b]	—	—
	Unconfined compression	7.6	3.0	—	—
	Direct shear	12.7	5.0	—	—
Disturbed	Water content	—	—	0.2	0.5
	Atterberg limits	—	—	0.2	0.5
	Shrinkage limits	—	—	0.2	0.5
	Specific gravity	—	—	0.1	0.2
	Grain-size analysis	—	—	0.2	0.5
Reconstituted	Standard compaction	—	—	13.5	30.0
	Permeability	—	—	0.9	2.0
	10.2-cm-diam consolidation	—	—	0.9	2.0
	Direct shear	—	—	0.9	2.0
	3.6-cm-diam triaxial (4 points)	—	—	0.9	2.0
	7.2-cm-diam triaxial (4 points)	—	—	4.5	10.0
	15-, 30-, or 38-cm-diam triaxial (4 points)	—	—	Coordinate with laboratory	
	Vibrated density	—	—	Coordinate with laboratory	

Equipment for Undisturbed Soil Sampling in Borings

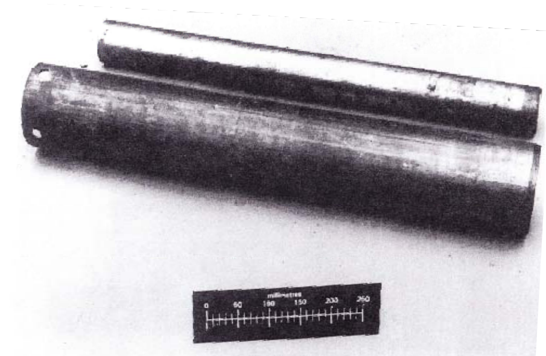


FIGURE 5-20. Sampling Tubes, 75 mm (3 in.) and 125 mm (5 in.) in Diameter

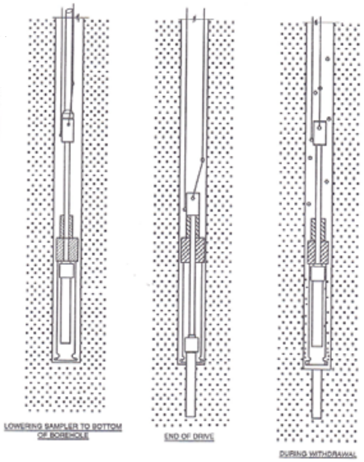


FIGURE 5-19. Operation of Bishop Sand Sampler (after Hvorslev 1949)

Procedures for Undisturbed Soil Sampling in Borings

- Advancing the borehole
  - Diameter of the borehole
    - ¼ to ¾ inch greater than sampler diameter
  - Methods of advance
    - Rotary drilling
    - Augers: for loose, moderately cohesive, moist soils
    - Hydraulic-piston sampler
    - Displacement methods
    - Percussion drilling

Procedures for Undisturbed Soil Sampling in Borings

- Stabilizing the borehole
  - Drilling mud
  - Casing
- Cleaning the hole before sampling
  - Cleaning with augers
  - Cleaning with rotary drilling methods

FIGURE 6-1. Screw-Type Earth Anchors

Procedures for Undisturbed Soil Sampling in Borings

- Sampling procedures
  - Push samplers
    - Methods of advance
    - Rate of penetration
    - Sampler withdrawal
    - Open-tube samplers
    - Piston samplers
  - Core-barrel samplers
  - Hollow-stem auger sampler

FIGURE 6-2. Screw-Type Earth Anchors Fastened to the Drill Rig with Load Binders to Anchor the Rig

Procedures for Undisturbed Soil Sampling in Borings

- Preservation of samples
  - Storing samples in sampling tubes
  - Removing samplers from sampling tubes

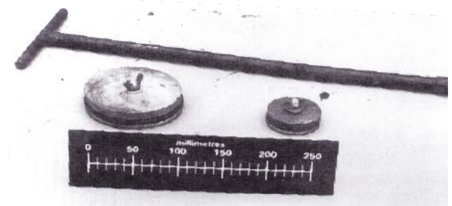
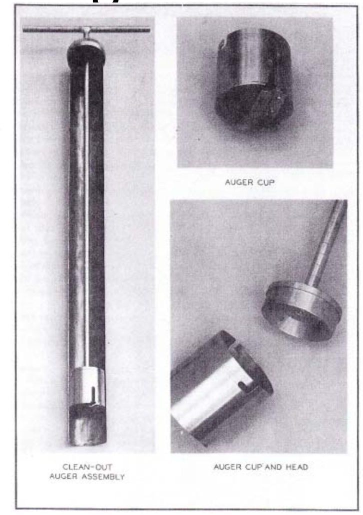


FIGURE 6-3. Expandable Packer



Cup Cleanout Auger, Used to Remove Material from the Bottom of the Sampling Tube

Procedures for Undisturbed Soil Sampling in Borings

- Boring and sampling records

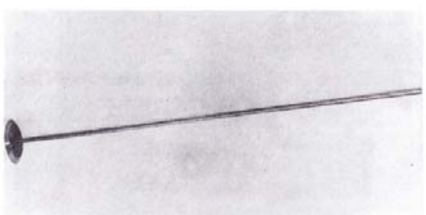


FIGURE 6-6. Sampling Tube Wall Scraper

FIGURE 6-5. Perforated Expandable Packer

- Shipment of Samplers

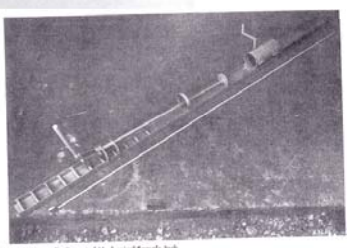
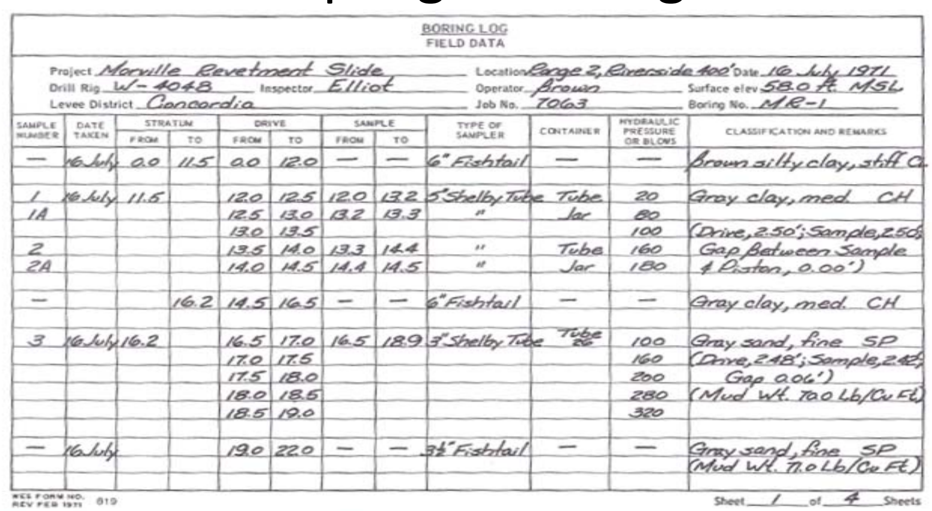


FIGURE 6-8. Manually Operated Mechanical Sample Jack

Hydraulic Sample Jack, Operated by the Hydraulic System of the Drill Rig

Procedures for Undisturbed Soil Sampling in Borings



BORING LOG
FIELD DATA

Project Marville Revetment Slide — Location Range 2, Riverside 400' — Date 16 July 1971
Drill Rig W-4048 — Inspector Elliot — Operator Brown — Surface elev 58.0 ft. MSL
Levee District Concordia — Job No. 7063 — Boring No. MR-1

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER	CONTAINER	HYDRAULIC PRESSURE OR BLOWS	CLASSIFICATION AND REMARKS
—	16 July	0.0	11.5	0.0	12.0	—	—	6" Fishtail	—	—	Brown silty clay, stiff C
1	16 July	11.6		12.0	12.5	12.0	13.2	5" Shelby Tube	Tube	20	Gray clay, med. CH
1A				12.5	13.0	13.2	13.3	"	Jar	80	
				13.0	13.5					100	(Drive, 2.50'; Sample, 2.50;
2				13.5	14.0	13.3	14.4	"	Tube	160	Gap Between Sample
2A				14.0	14.5	14.4	14.5	"	Jar	180	& Piston, 0.00')
—			16.2	14.5	16.5	—	—	6" Fishtail	—	—	Gray clay, med. CH
3	16 July	16.2		16.5	17.0	16.5	18.9	3" Shelby Tube	Tube 26	100	Gray sand, fine SP
				17.0	17.5					160	(Drive, 2.48'; Sample, 2.42;
				17.5	18.0					200	Gap 0.06')
				18.0	18.5					280	(Mud Wt. 70.0 Lb/Cu Ft)
				18.5	19.0					320	
—	16 July			19.0	22.0	—	—	3½" Fishtail	—	—	Gray sand, fine SP
											(Mud Wt. 71.0 Lb/Cu Ft)

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Sheet 1 of 4 Sheets

FIGURE 6-9. Example Boring Log of an Undisturbed Sample Boring

Detailed Site Investigations
Subsurface Investigations

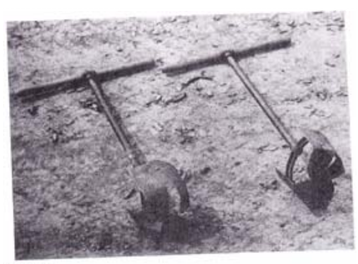
- Sampling: Disturbance of Samples
  - Disturbance of samples can happen due to:
    - Moisture loss
    - Moisture migration within the sample
    - Freezing
    - Vibration or shock during transportation (Cohesionless soil samples)
    - Chemical reactions between samples and their containers during storage

Detailed Site Investigations
Subsurface Investigations

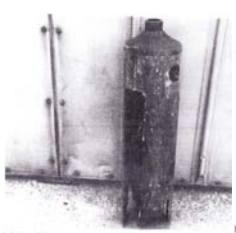
- Sampling: Disturbance of Samples
  - Moisture loss should be kept to a minimum
  - Moisture migration within the sample causes differential residual pore pressure to equalize with time
  - Clay/silt samples are highly affected by freezing
  - Chemical reactions between samples and their containers during storage affect soil plasticity, compressibility, or shear strength

Equipment for Disturbed Soil Sampling in Borings

- Sampler type
- Augers
  - Hand augers
  - Barrel augers
  - Helical augers
  - Bucket augers



Iwan Auger



McCart Split Barrel-Type Auger

FIGURE 7-2. Vicksburg Solid and Hinged Barrel-Type Augers

Equipment for Disturbed Soil Sampling in Borings

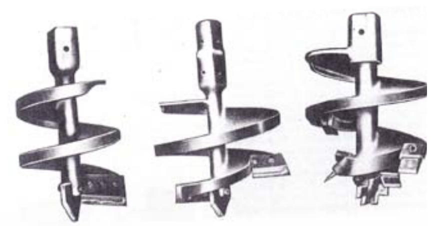


FIGURE 7-4. Short-Flight Solid-Stem Augers

FIGURE 7-5. Segments of a Continuous-Flight Solid-Stem Auger and a Continuous-Flight Hollow-Stem Auger

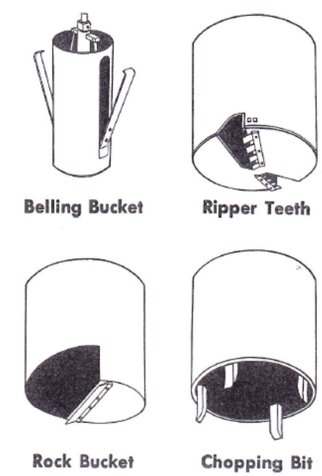


FIGURE 7-6. Isometric Drawing of Several Types of Bucket Augers

Equipment for Disturbed Soil Sampling in Borings

- Push or drive samplers
  - Open samplers
    - Thin-walled samplers
    - Thick-walled samplers
  - Piston samplers
- Displacement samplers
- Vibratory samplers

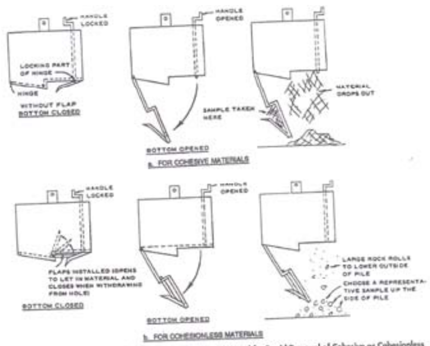


FIGURE 7-7. Schematic of Hinged Drop-Bottom Buckets, Designed for Rapid Removal of Cohesive or Cohesionless Soils

Equipment for Disturbed Soil Sampling in Borings

- Percussions samplers
  - Wireline samplers
  - Hammer drills

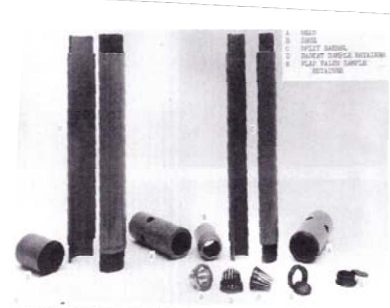


FIGURE 7-8. Two Split-Spoon Samplers and Second Sample Retainers


FIGURE 7-9. Portable Vibratory Sampler (after Smith, Dunbar, and Britsch 1986)

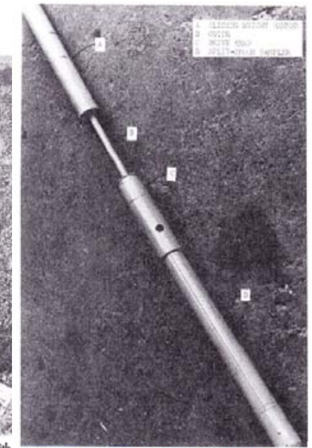


FIGURE 7-10. Split-Spoon Sampler with a New Orleans Wireline Drive Hammer

Procedures for Disturbed Soil Sampling in Borings

- Advancing the boreholes
  - Diameter of the borehole
    - At least ¼ inch greater than the sampler diameter
  - Methods of advance
    - Augering: where borehole remain open
    - Rotary drilling: rotation and application of downward pressure
    - Displacement methods
    - Percussion drilling

Procedures for Disturbed Soil Sampling in Borings

- Sampling procedures
  - Augers
  - Drive samplers
  - Displacement samplers
  - Vibratory samplers
  - Percussion samplers
- Boring and sampling records
  - All pertinent data must be recorded

Procedures for Disturbed Soil Sampling in Borings

- Preservation and shipment of samplers
  - Containers
    - Glass jar, cloth bags, or other suitable container
  - Sealing
    - Water content samples should be sealed
  - Identification: properly marked
  - Packing for shipment: protected from brokage
  - Methods of shipment:
    - A vehicle loaded and driven to the laboratory

Sampling Frozen Soils

- Drilling equipment
  - Drill bit: designed to resist impact loading the abrasive action of the soil

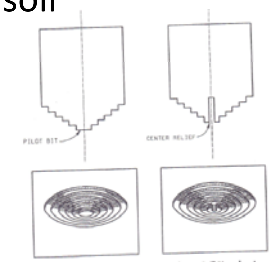


FIGURE 9-2. Schematic of the Step Configuration of the Cutting Teeth on a Drill Bit and an Isometric Drawing of Cut Surface at the Bottom of the Borehole

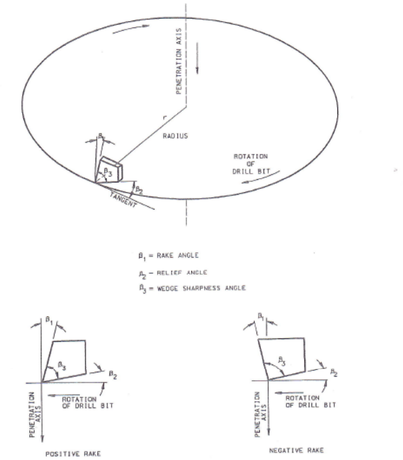


FIGURE 9-1. Schematic of a Cutting Tooth that Defines the Shape and Orientation of the Tooth (after Mellor 1976)

- Drilling equipment (Cont…)
  - Augers
    - Air pressure should be lower than 26 to 28 °F
  - Drilling fluids, fluid pumps, and refrigeration units
    - Drilling fluids at acceptable temperature, adequate pressure and rate of flow
    - Fluid pumps and air compressors for circulating liquid
    - Refrigeration units to chill the fluid
  - Other equipment
    - Split-ring or basket-type core lifters

Procedures for Disturbed Soil Sampling in Borings

- Drilling and sampling in frozen soil and ice
  - Advancing the borehole
    - Augering
    - Rotary drilling
  - Sampling
    - Sampling with augers
    - Sampling with core-barrel samplers

Underwater Sampling of Soils

- Depth of water 0-150 ft
- Underwater sediment types need appropriate equipments

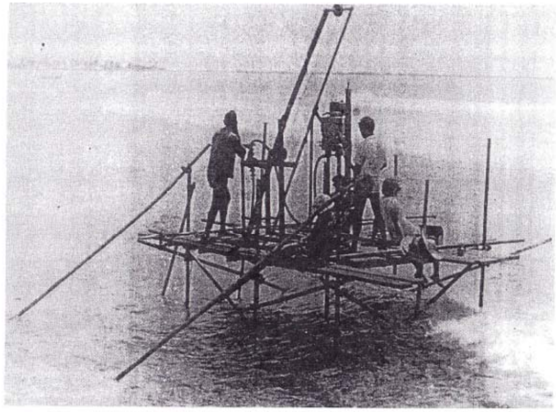


FIGURE 10-1. Small Drill Rig on a Scaffold
Note: Safety is a very important consideration for Corps of Engineers Projects. Safety items, including hardhats, gloves, safety shoes, protective clothing, life vests, and dust or vapor masks, should be worn, as appropriate, for the particular drilling and sampling operations. (Figure provided by the U.S. Naval Facilities Engineering Service Center)

Underwater Sampling of Soils

- Underwater samplers
  - Free samplers
    - Boomerang corer
    - Driven operated hand-held corers
    - ROV samplers

FIGURE 10-3. Sampler Being Deployed with a Mobile Crane Mounted on a Barge

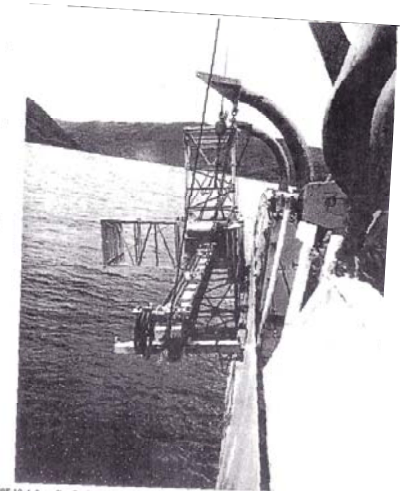


FIGURE 10-4. Sampling Device Hung from a Pair of Davits along the Side of a Vessel
(Figure provided by the U.S. Naval Facilities Engineering Service Center)

Underwater Sampling of Soils

FIGURE 10-6. Boomerang Corer
(Figure provided by the U.S. Naval Facilities Engineering Service Center)

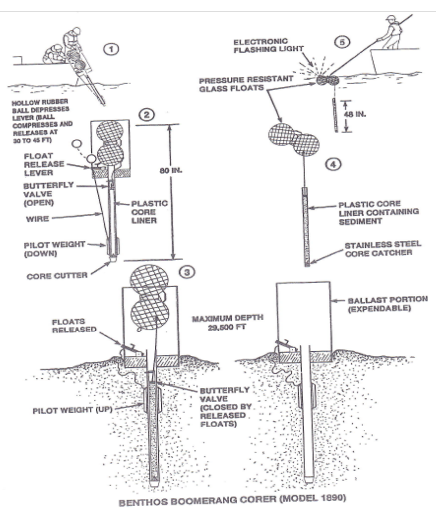
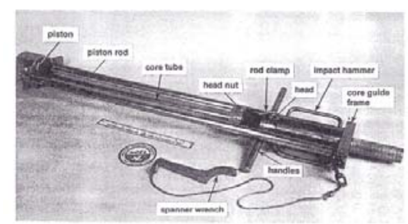


FIGURE 10-7. Operating Sequence of the Boomerang Corer
(Figure provided by the U.S. Naval Facilities Engineering Service Center)

Underwater Sampling of Soils

- Tethered samplers
  - Dredges and grab samplers
  - Box corers
  - Gravity corers
  - Vibratory corers
- Drill-string samplers



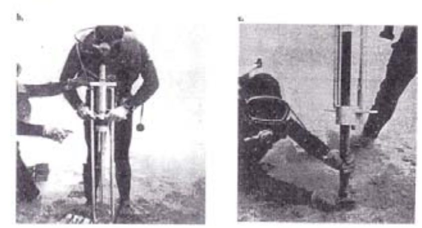


FIGURE 10-8. Hand-Held Diver-Operated Sampler Available to Government Agencies through the Naval Facilities Ocean Construction Equipment Inventory

Underwater Sampling of Soils

- Special considerations for underwater sampling
  - Equipment cleanup to remove sediment
  - Corrosion resistant materials
  - Wire rope corrosion
  - Sample liner damage
  - Core catcher
  - Location of the bottom
  - Gas-charges sediments
  - Sampling logs

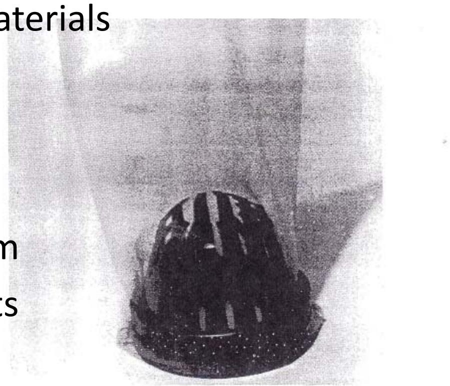


FIGURE 10-19. Finger-Type Sample Catcher with a Polyethylene Sleeve for Retaining Hard-to-Sample Materials

Sampling From Test Pits, Trenches, Accessible Borings, or Tunnels

TABLE 11-1. Accessible Excavations (After U.S. Department of the Interior, Bureau of Reclamation 1986)

Accessible Excavation	Procedure	Limitations	Comments
Test pit	Excavate a rectangular or square pit by hand or with power equipment. Minimum dimensions are on the order of 1 × 1.5 m (3 × 5 ft).	Economical limit of depth is about 6 to 9 m (20 to 30 ft) or to the water table. If deeper than 1.2 m (4 ft), support or slope the walls of the excavation.	Samples from a test pit are usually more expensive than samples obtained from conventional drilling and sampling operations. Sampling by hand may be the only method of obtaining representative samples of certain soils.
Trench	Excavate a rectangular or trapezoidal (cross-section) trench by hand or with power equipment. Minimum dimension of the excavation should not be less than 1 to 2 m (3 to 6 ft) wide. Length may be extended as required.	Depth of trench is usually fairly shallow, but may be 6 to 9 m (20 to 30 ft) or to the water table. If deeper than 1.2 m (4 ft), support or slope the walls of the excavation.	Provides a continuous two-dimensional soil profile. This method is perhaps the most economical and comprehensive technique for shallow explorations of foundation, borrow, or aggregate material.
Accessible boring	Special-purpose drilling equipment, such as large-diameter bucket augers, may be used to drill accessible boreholes to a depth of about 30 m (100 ft). The minimum diameter is about 0.6 m (2 ft), although a larger diameter may be required for adequate work space.	Accessible boreholes deeper than 1.2 m (4 ft) should be cased with steel pipe. Holes may be cut into the pipe to permit inspection and sampling of the sidewalls of the excavation.	If power equipment is available and the area is accessible, large-diameter boreholes can be made more rapidly and at less cost than excavating test pits by manual methods.
Tunnel	Excavate a rectangular-shaped tunnel by hand or with power equipment. Minimum dimensions are on the order of 1.5 × 2.1 m (5 × 7 ft), although the dimensions may be increased when power mucking and hauling equipment are used.	Tunneling is expensive and therefore should be used only under special conditions. The roof and walls of the tunnel require a support system.	Must provide underground lighting and ventilation system.

Sampling From Stockpiles and Bins, Transportation Units, or Conveyor Belts

- Sampling from:
  - Loaded freight cars or trucks
    - Power drilling and sampling equipment
  - Conveyor belts
    - Three points: points of material discharge to and from the belt and intermediate point of the belt
  - Storage bins: Point of discharge from storage facility

Sampling From Stockpiles and Bins, Transportation Units, or Conveyor Belts

- Sampling (cont…)
  - Stockpiles:
    - along periphery of stockpile
  - Roadways
    - Hand sampling
  - Quarries and borrow pits
    - Site dependent

- Required volume of samples

TABLE 12-1. Minimum Field Sampling Masses (after ASTM D 75-87 [ASTM 1992a, 1992b, 1993])

Nominal Size of Aggregate	Minimum Mass of Sample (kg)
Fine aggregate	
No. 8 (2.36 mm)	10 (25 lb)
No. 4 (4.75 mm)	10 (25 lb)
Coarse aggregate	
9.5 mm (3/8 in.)	10 (25 lb)
12.5 mm (1/2 in.)	15 (35 lb)
19.0 mm (3/4 in.)	25 (55 lb)
25.0 mm (1 in.)	50 (110 lb)
37.5 mm (1-1/2 in.)	75 (165 lb)
50 mm (2 in.)	100 (220 lb)
63 mm (2-1/2 in.)	125 (275 lb)
75 mm (3 in.)	150 (330 lb)
90 mm (3-1/2 in.)	175 (385 lb)

Detailed Site Investigations

Subsurface Investigations

- Sampling: Borrow Materials
  - – Location and amount of available borrow materials should be determined using horizontal and vertical intervals
  - – Boundaries of unsuitable materials should be outlined by means of borings and representative sampling and testing and used to define the required excavation limits

Detailed Site Investigations

Subsurface Investigations

- Transportation and Storage of Samples
  - – To minimize Transportation and storage impact on samples
    - Keep storage room temperature above 4 °C to avoid freezing of clay or silt samples
    - Design transportation to avoid vibration or shock
    - Keep samples in the same orientation as that in which they were sampled and well padded for isolation from vibration and impact
    - Select the correct material of the sample container

Handling and Storage of Samples and Sampling Records

- Handling and storage
  - – Soil samples can be divided into four groups
    - Group A: samples for visual classification
    - Group B: samples for water content and classification tests
    - Group C: undisturbed samples
    - Group D: fragile or highly sensitive undisturbed samples
  - – Removal of sample from sampling device without shocks
  - – Identification of samples

Handling and Storage of Samples and Sampling Records

- Handling and storage
  - – Labeling samples:
    - Project name
    - Boring Number
    - Soils description
    - Lengths, orientation, and method of sampling
    - Special instructions

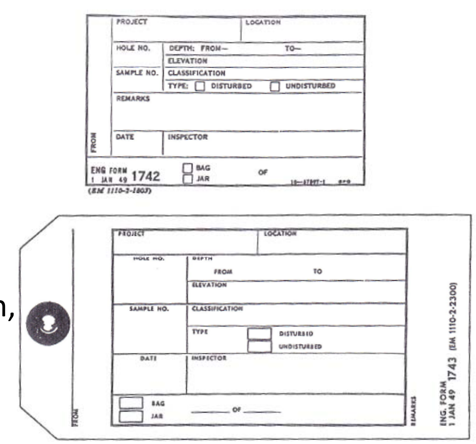


FIGURE 13-1. ENG Forms 1742 and 1743 for Labeling and Identifying Soil Samples

Handling and Storage of Samples and Sampling Records

- Handling and storage
  - Preserving samples by sealing them in a container
    - Group A: any type of container
    - Group B: sealed moisture-proof container
    - Groups C&D: protected from changes in water content, shock, vibration, temperature extremes, and chemical changes

Handling and Storage of Samples and Sampling Records

- Handling and storage
  - Transporting samples
    - Group A and B: in any type of transportation
    - Groups C and D: in wood or metal with foam, rubber, or polystrene under the supervision to prevent rolling and be protected against vibration, shock, and temperature extremes
  - Storage
    - Moist, cool, frost-free environmental room maintained at 100% relative humidity and 2-4 °C

Handling and Storage of Samples and Sampling Records

- Written Record – boring logs
  - Location and position of each borehole
  - Material, samples obtained,
  - depth and length of samples
  - Equipment used, etc

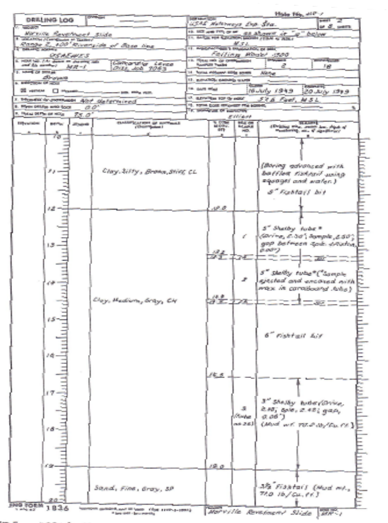
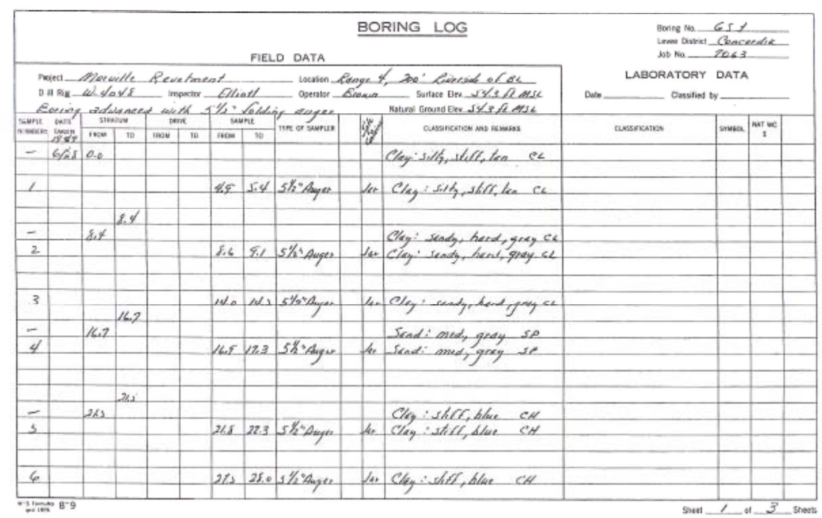


FIGURE 13-2. ENG Form 1836 for Maintaining a Record of Drilling and Undisturbed Sampling Operations

Handling and Storage of Samples and Sampling Records



BORING LOG

Boring No. 65 1
Levee District Concordia
Job No. 7063

FIELD DATA

Project Morville Revetment Location Range 4, 300' Riverside of BL
Drill Rig W. 4o4E Inspector Elliott Operator Brown Surface Elev. 54.3 ft MSL
Boring advanced with 5½" folding auger Natural Ground Elev. 54.3 ft MSL

LABORATORY DATA

Date ______ Classified by ______

Sample Number	Date Taken 1949	Stratum From	Stratum To	Drive From	Drive To	Sample From	Sample To	Type of Sampler		Classification and Remarks	Classification	Symbol	Nat WC %
–	6/28	0.0								Clay: silty, stiff, tan CL			
1						4.9	5.4	5½" Auger	Jar	Clay: silty, stiff, tan CL			
			8.4										
–		8.4								Clay: sandy, hard, gray CL			
2						8.6	9.1	5½" Auger	Jar	Clay: sandy, hard, gray CL			
3						14.0	14.3	5½" Auger	Jar	Clay: sandy, hard, gray CL			
			16.7										
–		16.7								Sand: med, gray SP			
4						16.9	17.3	5½" Auger	Jar	Sand: med, gray SP			
			21.5										
–		21.5								Clay: stiff, blue CH			
5						21.8	22.3	5½" Auger	Jar	Clay: stiff, blue CH			
6						27.5	28.0	5½" Auger	Jar	Clay: stiff, blue CH			

B-9

Sheet 1 of 3 Sheets

FIGURE 13-3. Engineering Form for Keeping a Record of Disturbed Sampling Operations

Detailed Site Investigations

Subsurface Investigations

- In Situ Testing
  - Conducted using boreholes, excavations, test pits, and trenches for definition of foundation properties
  - In situ tests are often the best means to determine the engineering properties of subsurface materials
  - Can be used for soils and rocks that cannot be sampled and transport for laboratory analysis

Detailed Site Investigations

Subsurface Investigations

- In Situ Testing
  - Determine in situ stresses and deformation properties, including the shear strength of the jointed rock mass
  - Measure strength and residual stresses along discontinuities or weak seams in the rock mass
  - Direct shear strength tests in rock measure peak and residual direct shear strength as a function of normal stress on the shear plane

Detailed Site Investigations

Subsurface Investigations

- In Situ Testing
  - Tables showing methods of in situ testing of soil and rock to determine
    - Shear strength
    - Stress conditions
    - Deformation characteristics
    - Bearing capacity
    - Relative density
    - Liquefaction susceptibility

Detailed Site Investigations

Subsurface Investigations

Methods of In Situ Testing of Soil and Rock

Standard Penetration Test (SPT)	Cone Penetration Test (CPT)	Field vane shear test	Drive point penetrometer	Plate bearing test (soil)	Plate bearing test
or Plate jacking test (rock)	Pressure meter test	Field pumping test	Borehole field permeability test	Direct shear test	Pressure tunnel test
Radial jacking test	Borehole jack test	Borehole deformation meter	Inclusion stressmeter	Borehole strain gauge	Hydraulic fracturing test
Crosshole seismic test	Uphole/ downhole seismic test	Acoustic velocity log	3-D velocity log	Electrical resistivity log	Neutron log
Gamma-gamma log (Density log)	Borehole cameras	Borehole televiewer			

Procedure, applicability and limitations are available in Appendix C of RG 1.132

Detailed Site Investigations
Subsurface Investigations

- In Situ Testing

Appendix F of RG 1.132

In Situ Tests to Determine Shear Strength

Test	Soil	Rock
Standard penetration test (SPT)	X	
Direct shear	X	X
Field vane shear	X	
Plate bearing	X	X
Uniaxial compression		X
Cone penetration test (CPT)	X	
Borehole direct shear	X	
Pressuremeter		X
Borehole jacking		X

Detailed Site Investigations
Subsurface Investigations

- In Situ Testing

Appendix F of RG 1.132

In Situ Tests to Determine Stress Conditions

Test	Soil	Rock
Hydraulic fracturing	X	X
Vane shear	X	
Overcoring techniques		X
Flatjacks		X
Uniaxial (tunnel) jacking	X	X
Pressuremeter	X	X
Borehole jacking		X
Chamber (gallery) pressure		X

Detailed Site Investigations
Subsurface Investigations

- In Situ Testing

Appendix F of RG 1.132

In Situ Tests to Determine Deformation Characteristics

Test	Soil	Rock
Geophysical refraction	X	X
Pressuremeter	X	X
Chamber test	X	X
Flatjacks		X
Uniaxial (tunnel) jacking	X	X
Plate bearing	X	X
Borehole jack		X
Standard penetration test (SPT)	X	

Detailed Site Investigations
Subsurface Investigations

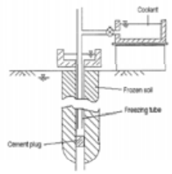
- In Situ Testing

Appendix F of RG 1.132

In Situ Tests to Determine Other Characteristics

Purpose of Test	Test	Soil	Rock
Bearing capacity	Plate bearing	X	X
	Standard penetration test (SPT)	X	
Relative density	Standard penetration test (SPT)	X	
	In situ sampling	X	
Liquefaction susceptibility	Standard penetration test (SPT)	X	
	Cone penetration test (CPT)	X	
	Shear wave velocity (vs)	X	

Detailed Site Investigations
Subsurface Investigations



- In Situ Testing
  - Standard penetration test (SPT)
    - a soil index test used to obtain the resistance to penetration by counting the number of blows required to drive a steel tube of specific dimensions into the subsoil a specified distance using a hammer of a specified weight
    - Used in determining shear strength, bearing capacity, mass deformability, relative density, and liquefaction susceptibility

Video: Standard Penetration Test (SPT) Demonstration2

Detailed Site Investigations
Subsurface Investigations

- In Situ Testing
  - Cone penetration test (CPT)
    - An in-situ testing method for evaluating detailed soil stratigraphy as well as estimating geotechnical engineering properties
    - Involves pushing a 1.4-inch-diameter instrumented probe into the earth while performing two measurements: cone tip bearing resistance and sleeve friction resistance
    - Provides continuous penetration resistance profiles for soils (detect soft or weak layers) and quantify undrained strength trends with depth

Primary Video: CPT testing with low cost unit2

Secondary Video: CPT (Cone Penetration Test) - Soiltest Italia

Detailed Site Investigations
Subsurface Investigations

- In Situ Testing
  - Interpretation of in situ test results in soils, clay shales, and moisture-sensitive rocks requires consideration of drainage that may occur during the test that include
    - unconsolidated- undrained conditions,
    - consolidated-undrained conditions,
    - consolidated-drained conditions,
    - unconsolidated-drained conditions,
    - intermediate conditions between these limiting states

Detailed Site Investigations
Subsurface Investigations

- In Situ Testing
  - In situ tests in rock are used to
    - Determine in situ stresses and deformation properties, including the shear strength of the jointed rock mass
    - Measure strength and residual stresses along discontinuities or weak seams in the rock mass
  - Direct shear strength tests in rock measure peak and residual direct shear strength as a function of normal stress on the shear plane

Detailed Site Investigations

Geophysical Investigations

- Geophysical Investigation
  - Include surface geophysics, borehole logging, and cross-borehole measurements
  - Used to fill in information between surface outcrops, trenches, and boreholes
  - Geophysical investigation methods can be used for
    - Location and correlation of geologic features
    - In situ measurement of elastic moduli and densities
    - Detection of hidden cultural features

Detailed Site Investigations

Geophysical Investigations

- Surface Geophysical Investigation Methods
  - Example surface geophysical methods: seismic refraction, reflection surveys, surface electromagnetic, electrical resistivity surveys, gravity , magnetics, ground penetrating radar (GPR)
  - Spectral Analysis of Surface Waves (SASW): used to measure shear-wave velocity profiles and evaluate elastic moduli and layer thicknesses of soil profiles

Detailed Site Investigations

Geophysical Investigations

Surface Geophysical Methods for Determination of Engineering Parameters

- Refraction (seismic)
- Reflection (seismic)
- Rayleigh wave dispersion
- Vibratory (seismic)
- Reflection profiling (seismic-acoustic)
- Electrical resistivity
- Acoustic (resonance)
- Ground penetrating radar(GPR)
- Gravity
- Magnetic
- Uphole/ downhole (seismic)
- Crosshole (seismic)
- Borehole spontaneous potential

Details on applications, advantages and limitations are available in Appendix E of RG 1.132

Detailed Site Investigations

Geophysical Investigations

- Borehole Geophysical Investigation
  - Boreholes should be logged with a suitable suite of geophysical logging methods
  - Borehole logs are useful for determining lithological, hydrological, engineering properties of subsurface horizons, and correlating stratigraphic horizons between boreholes
  - Tomographic methods can provide a detailed picture of geophysical properties between boreholes

Detailed Site Investigations

Geophysical Investigations

- Borehole Geophysical Investigation
  - Crosshole geophysical measurements may be used to obtain detailed information on the region between two boreholes and to derive engineering and hydrogeologic properties, such as shear modulus, porosity, and permeability
  - Used for measuring shear- and compressional-wave velocities (most common)
  - Electrical resistivity and electromagnetic methods may be employed

Detailed Site Investigations

Geophysical Investigations

Borehole Geophysical Methods for Determination of Engineering Parameters

Single-point resistivity	Long and shortnormal resistivity	Lateral resistivity	Induction resistivity	Borehole imagery (acoustic)
Continuous sonic (3-D) velocity	Natural gamma radiation	Gamma-gamma density	Neutron porosity	Neutron activation
Borehole magnetic	Mechanical caliper	Acoustic caliper	Temperature	Fluid resistivity
Tracers	Flowmeter	Borehole dipmeter	Downhole flow meter	

Details on applications, advantages and limitations are available in Appendix E of RG 1.132

Detailed Site Investigations

Geophysical Investigations

- Borehole Geophysical Investigation
  - Acoustic borehole logging in rock provide a suitable approximation of shear modulus even under higher strain conditions
  - High strain shear-wave methods (crosshole) in soil are usually ineffective

Detailed Site Investigations

Logs of Subsurface Investigations

- Logs of Subsurface Investigations
  - The location of all explorations should be recorded in the GIS and shown on geologic cross-sections, together with elevations and important data
  - Logs of exploratory trenches and other excavations should be presented in a graphic format in which important components of the soil and rock are shown in sufficient detail to permit independent evaluation
  - Information to be included in boring logs

Detailed Site Investigations

Logs of Subsurface Investigations

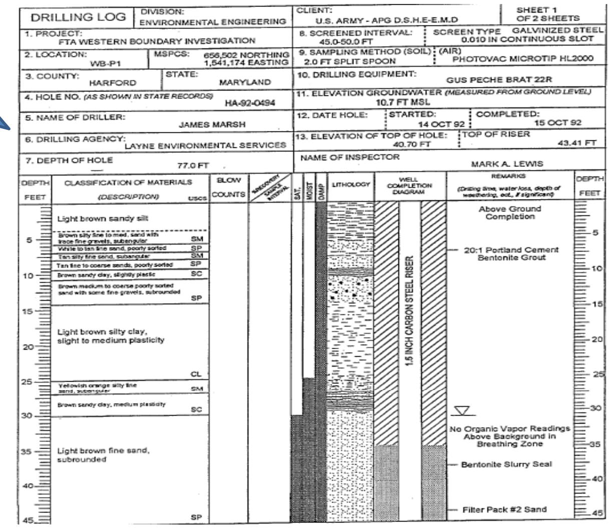
Information Contained in Boring logs

Boring date	Boring location	Boring depths	Elevations of top and bottom of borings	Elevations of soil or rock strata boundaries
Water table level	Classification and description of soil and rock layers	Blow count values obtained from Standard Penetration Tests	Percent recovery of rock core	Quantity of core not recovered for each core interval
Rock quality designation (RQD)	Results of field permeability tests and geophysical borehole logging	Type of tools used in making the boring	Other special features or occurrences	Notes f everything significant to the interpretation of subsurface conditions

Detailed Site Investigations

Logs of Subsurface Investigations

Example of boring log data representation



Groundwater Investigations

- Groundwater conditions should be observed during the course of the site investigation, and measurements should be made of the water level in exploratory borings
- Knowledge of groundwater relationship to surface waters, and variations associated with seasons or tides
- Assessment of groundwater conditions are observed in borings at the time they are made and in wells or piezometers at regular intervals

Groundwater Investigations

- The groundwater or drilling mud level in exploratory borings should be measured
  - at the start of each workday for borings in progress
  - at the completion of drilling
  - when the water levels in the borings have stabilized

Groundwater Investigations

- Groundwater level assessment tools
  - Existing wells located during field geologic reconnaissance
  - Water levels recorded on drilling logs
  - Installing piezometers and observation wells
  - Water elevation, flow rate, and temperature of springs and surface water
  - Tracer testing
  - Geophysical methods such as seismic refraction

Groundwater Investigations

- Groundwater studies can be used to obtain information about:
  - Position and thickness of aquifers and confining beds (aquicludes)
  - Transmissivity, storage coefficient, location and nature of aquifer boundaries
  - Hydraulic characteristics of aquicludes

Groundwater Investigations

- Appendix G to this guide lists Types of instruments for measuring groundwater pressure and their advantages and limitations.
- ASTM D 5092-95 provides guidance on the design and installation of groundwater monitoring wells

Groundwater Investigations

Instruments for Measuring Groundwater Pressure

- Observation well
- Open standpipe piezometer
- Twin-tube hydraulic piezometer
- Pneumatic piezometer
- Vibrating wire piezometer
- Unbonded electrical resistance piezometer
- Bonded electrical resistance piezometer
- Multipoint piezometer, with packers
- Multipoint piezometer, surrounded with grout
- Multipoint push-in piezometer
- Multipoint piezometer, with movable probe

Groundwater Investigations

- Piezometers or wells should be installed in as many locations as needed to adequately define the groundwater environment
- Pumping tests are a preferred method for evaluating local permeability characteristics and assessing dewatering requirements for construction and operation of the plant

Groundwater Investigations

- Piezometers or observation wells should be used
  - during construction where construction dewatering is required to monitor the groundwater surface and pore pressures beneath the excavation and in the adjacent ground
  - When the possibility of perched groundwater tables or artesian pressures is indicated by borings or other evidence (measured independently)

Groundwater Investigations

- Care should be taken in the design and installation of piezometers to prevent hydraulic communication between aquifers
- The occurrence of artesian pressure in borings should be noted on boring logs, and the artesian heads should be measured and logged

Construction Mapping

- All construction excavations for safety-related structures should be mapped and logged in detail including
  - Features requiring excavation
  - Features that important to foundation behavior undetected in the investigation
  - Changes in foundation design
  - Newly discovered geologic features

Construction Mapping

- Features found or installed should be surveyed and entered into maps, cross-sections, and the database
- Photographic or videographic records of foundation mapping and treatment should be made
- GIS and other databases should be continuously updated up to the construction phase

Construction Mapping

- Appendix A to NUREG/CR-5738 provides detailed guidance on technical procedures for mapping foundations
- Mapping of tunnels and other underground openings must be planned differently from foundation mapping [Appendix B to NUREG/CR-5738]

Support Functions

Surveying/Mapping/GIS

- Surveying/Mapping/GIS
  - Surveying should accompany all phases of site investigation and construction
  - Surveying methods range from triangulation or plane table work (for mapping small areas) to electronic distance and GPS measurements
  - GPS or DGPS (differential GPS) together with automated recording and computing procedures is the most suitable method

Support Functions

- Surveying/Mapping/GIS
  - GPS measurements and surveyed locations should be tied to National Geodetic Survey (NGS) markers to be compatible with topographic maps and digital maps
  - A suitable coordinate system for the site should be chosen (World Geodetic System of 1984 (WGS 84), the International Terrestrial Reference Frame (ITRF), and the North American Datum of 1983 (NAD 83))

Support Functions

- Database/Sample Repository/Quality Assurance
  – All data acquired during site investigation such as logs of operations, photographs, test results, and engineering evaluations should be organized into suitable categories in accordance with quality assurance principles and procedures and entered into a GIS database to permit visual display in maps and cross sections

Support Functions

- Database/Sample Repository/Quality Assurance
  – The site investigations should be included in the overall Quality Assurance program for plant design and construction according to the guidance in Regulatory Guide 1.28 and the requirements of Appendix B to 10 CFR Part 50. Field operations and records preservation should, therefore, be conducted in accordance with quality assurance principles and procedures

3000. Site Investigation

3100
- Site Investigation for Foundations of Nuclear Power Plants

3200
- Laboratory Investigations and Soil Sampling of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

3200. Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

- Laboratory Testing Program
- Soil Samples
- Selection and Preparation of Test Specimens
- Testing Procedures For Determining Soil Properties

3200. Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

- Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design based on:
  - Regulatory Guide 1.138 that describes acceptable laboratory investigations and testing practices for determining soil and rock properties and characteristics needed for engineering analysis and design for foundations and earthworks for nuclear power plants
  - NUREG/CR-5739 (1999) that summarizes the processes required in a laboratory testing program

3200. Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

- Purpose:
  - To identify and classify soils and rocks and to evaluate their physical and engineering properties

Laboratory Testing Program

- Laboratory facilities should have
  - Adequate test space, temperature controlled areas, and adequate ventilation and air flow
  - Separate areas for dust- and vibration-producing activities such as sieve analyses, compaction tests, and sample processing
  - Separate room with about 100% relative humidity for storing samples if storage is needed
  - Proper equipment to perform the tests

Laboratory Testing Program

- Laboratory Equipment:
  - Test Apparatus
    - Should conform to the standard specifications
    - Description of essential characteristics if not standard
    - Inspected and maintained regularly
  - Calibration of Test Apparatus
    - Pre-service calibration of test apparatus
    - Recalibration at intervals frequency according to the susceptibility to change and precision of measurement

3200. Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

- Laboratory Testing Program
- Soil Samples
- Selection and Preparation of Test Specimens
- Testing Procedures For Determining Soil Properties

Soil Samples

- Handling and Storage of Samples
  - Verifying the identification markings of all samples immediately upon their arrival at the laboratory
  - An inventory should be maintained of all samples received

Soil Samples

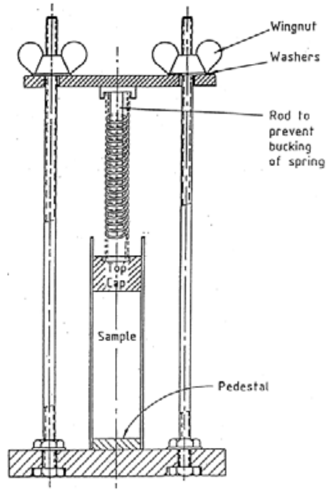
- Handling and Storage of Disturbed Samples
  - Should be examined and tested after arrival in the laboratory
  - Storage of the samples may be required for several days or weeks for a large testing program
  - Samples to be used for fluid content determinations should be protected against change in water content

Soil Samples

- Handling and Storage of Undisturbed Samples
  - Should be protected from vibration, shock, significant temperature changes, and changes in water content
  - Should be stored in humid rooms
  - Moisture seals should be checked periodically and renewed as needed
  - Should not be retained for long periods

Soil Samples

- Handling and Storage of Undisturbed Samples
  - Duration of storage before testing should be recorded for each sample test
  - A sample compressor was found to be useful in prevent deterioration of clay samples during storage (Brown and Chow (1988))



Soil Samples

- Handling and Storage of Rock Samples
  - Should be transported as fragile material and protected from excessive changes in humidity and temperature
  - Should be examined and tested as soon as possible
  - May be stored for a large testing program and protected against damage

Soil Samples

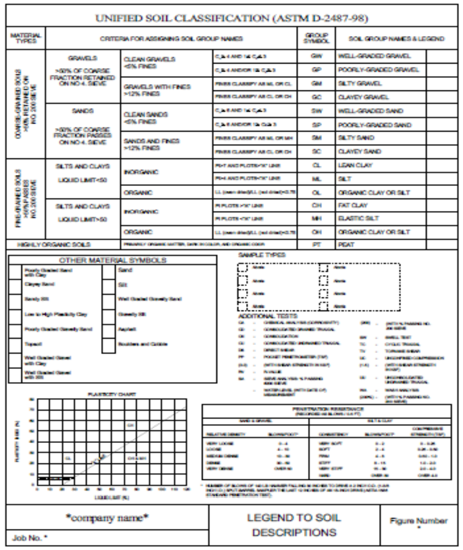
- Initial Identification and Examination of Samples
  - ASTM D 2488: Practice for Description and Identification of Soils
    - Procedures for the description and identification of a soil sample based primarily on visual identification and manual test to aid in the evaluation of its significant properties for engineering
    - Grouping similar soil samples so that only a minimum number of laboratory tests need be run

Soil Samples

- Initial Identification and Examination of Samples
  - ASTM D 4452: X-Ray Radiography of Soil Samples
    - Procedures for the detection of inherent abnormalities and disturbances
    - Enables the user to determine the effects of sampling and natural variations within samples as identified by the extent of the relative penetration of X-rays through soil samples

Soil Samples

- Initial Identification and Examination of Samples
  - ASTM D 2487: Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)
    - soil groups and method of identification in a uniform classification procedure



Soil Samples

- Initial Identification and Examination of Samples
  - RTH 102-93: Rock Testing Handbook, 1993
    - Procedures used in the petrographic examination of rock core samples
    - Determines the physical and chemical properties of a material
    - Describes and classifies a sample
    - Determines the amount of specific materials that may affect the specimen's intended use

3200. Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

- Laboratory Testing Program
- Soil Samples
- Selection and Preparation of Test Specimens
- Testing Procedures For Determining Soil Properties

Selection and Preparation of Test Specimens

- Selection of soil and rock specimens for laboratory testing requires careful examination of boring records and available samples
- Test specimens should be accurately described and representative of the soil or rock unit to permit establishment of the soil profile
- Average and variability range of test values for material properties should be identified

Selection and Preparation of Test Specimens

- Testing should be of the most representative samples, those with extreme properties and those representative of critical zones
- High-quality undisturbed samples are preferred for all tests of strength and dynamic responses of in situ soils
- Undisturbed test samples should be prepared in a humid room to preserve the natural structure and water content of the material

Selection and Preparation of Test Specimens

- Undisturbed Samples
- Reconstituted or Remolded Samples
- Scalping of Large Particles
- Laboratory Testing Program

Selection and Preparation of Test Specimens

- Test Specimens of Undisturbed Samples
  - Undisturbed tube samples of soils should be examined for evidence of disturbance
  - To minimize damage during the removal of a sample from the sample tube, split the tube longitudinally by milling, or saw the tube transversely into segments of sufficient length to extrude a single test specimen from each and trim off the ends

Selection and Preparation of Test Specimens

- Undisturbed tube samples should satisfy the following criteria:
  (1) The specific recovery ratio should be between 90 and 100 percent
  (2) No visible distortions, planes of failure, pitting, discoloration, or other signs of disturbance on the surface of or in sliced sections of the sample
  (3) No change in the sample net length and weight and results of other control tests during shipment, storage, and handling

Selection and Preparation of Test Specimens

- Test Specimens of Undisturbed Samples
  - Samples that have been subjected to violent mechanical shocks or to accidental freezing and thawing should not be considered to be undisturbed
  - Test specimens should be representative of each discrete soil or rock unit to be tested and should be accurately described on the basis of classification tests to permit establishment of the soil and geologic profiles

Selection and Preparation of Test Specimens

- Test Specimens of Undisturbed Samples
  - The best quality and most representative undisturbed samples available should be used in physical and engineering property tests of in situ soils
  - Trimming and shaping of test specimens of soils require great care to prevent disturbance and changes in water content
  - Frozen samples should be prepared under conditions that will prevent premature thawing

Selection and Preparation of Test Specimens

- Test Specimens of Undisturbed Samples
  - EM 1110-2-1906: Laboratory Soils Testing
    - Describes procedures for preparing soil samples for testing for making determinations of the soil properties
  - ASTM D 4452: X-Ray Radiography of Soil Samples
    - Can be used to determine the quality of a sample before testing
  - High-quality undisturbed samples are preferred for all tests of strength and dynamic responses of in situ soils, whether cohesive or cohesionless

Selection and Preparation of Test Specimens

- Test Specimens of Reconstituted or Remolded Samples
  - Used when representative undisturbed samples cannot be obtained
  - Remolded samples are used as representative of compacted fill or backfill material for new construction
  - Undisturbed samples of earth fill are taken for confirmatory testing during construction

Selection and Preparation of Test Specimens

- Test Specimens of Reconstituted or Remolded Samples
  - Undisturbed samples are also taken in the testing and reevaluation of existing structures
  - Reconstituted specimens representative of in situ material should be molded to the in situ density and moisture content as determined from actual field measurements
  - Fill material samples should be molded to the range of densities and water contents under field conditions

Selection and Preparation of Test Specimens

- Test Specimens of Reconstituted or Remolded Samples
  - Laboratory personnel should record a complete detailed description of the specimen
    - identification of the material, color, consistency, brittleness of the material, and indication of disturbance of boring samples
  - Disturbed samples should not be used for any test other than classification, specific gravity, or water content

Selection and Preparation of Test Specimens

- Scalping of Large Particles
  - Gravel and large particles are typically scalped, or removed from the total sample, and the finer fraction tested
  - Laboratory investigations depend on the design requirements and nature of problems encountered or suspected at the site

Selection and Preparation of Test Specimens

- Laboratory Testing Program
  - Study of soil and rock mechanics includes investigation, description, classification, testing, and analysis of soil and rock to determine their interaction with structures built in or upon them, or built with them
  - Carrying out tests on samples of soil in a laboratory to determine physical properties of soils and rocks

Selection and Preparation of Test Specimens

- Laboratory Testing Program
  - Physical properties of soils and rocks should be determined by carrying out two main categories of tests on samples of soil in a laboratory
    - Classification tests indicate general type of soil and engineering category to which it belongs
    - Engineering properties tests require careful considerations of field conditions, various design loading conditions, material properties, and possible problems at the site.

Selection and Preparation of Test Specimens

- Laboratory Testing Program
  - Investigation and evaluation of sites for nuclear power plants require the evaluation of
    - Site response to earthquake loading and other dynamic loading conditions and analysis of earthquake loading effects on the stability of slope and embankments
    - Wave propagation characteristics of subsurface materials with interaction effects of structures
    - Analysis of the potential for soil liquefaction, settlement under dynamic loading, and

Selection and Preparation of Test Specimens

- Laboratory Testing Program
  - Basic parameters required as input for dynamic response analyses of soils include
    - Total mass density, relative density, Poisson's ratio, static soil strength, initial stress conditions, shear and compressional wave velocities, and the dynamic shear modulus and damping ratio
    - Variation of strength, moduli, and damping with strain

3200. Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants

- Laboratory Testing Program
- Soil Samples
- Selection and Preparation of Test Specimens
- Testing Procedures For Determining Soil Properties

Testing Procedures For Determining Soil Properties

- Testing Procedures For Determining Static Soil Properties
- Testing Procedures For Determining Dynamic Soil Properties
- Testing Procedures For Determining Engineering Properties of Rock

Testing Procedures For Determining Static Soil Properties

- Laboratory tests on soil and rock material should be thorough and of documented quality to permit a realistic estimate of properties and subsurface conditions
- Laboratory Personnel should be responsible for handling samples, preparing test specimens, specifying testing procedures and operations, with all related Documentation

Testing Procedures For Determining Static Soil Properties

- Soil Testing
  - Classification tests and determination of engineering properties should be performed according to an accepted and published method.
  - Laboratory procedures for some of the most common tests, along with other related references, are shown in Appendix A to RG 1.138

Testing Procedures For Determining Static Soil Properties

- Soil Testing: Most common soil tests include

Water Content	Permeability
Unit Weights	Consolidation
Void Ratio	Direct Shear Test
Porosity	Triaxial Compression Tests
Saturation	Unconfined Compression Tests
Atterberg Limits	Relative Density
Specific Gravity	Grain Size Analysis
Erodibility Tests	Compaction

Testing Procedures For Determining Static Soil Properties

- Soil Testing
  - The number of tests required depends on the type of material, the quality of samples, the purpose and relative importance of the test, and the scatter of test data
  - All soils and rocks sampled at the site should first be identified and classified using appropriate index and classification tests

Testing Procedures For Determining Static Soil Properties

- Soil Testing
  - A sufficient number of tests for physical and engineering properties should be completed to define the range of values for material properties expected under field conditions
  - Standard test procedures and equipment require documentation by reference only while non-standard test procedures or equipment should be documented in detail

Testing Procedures For Determining Static Soil Properties

- Soil Testing
  - The Unified Soil Classification System (ASTM D 2487) should be used in describing soils and in preparing soil profiles
  - ASTM D 5878 should be used for the classification of rock mass for specific engineering purposes
  - Standard test procedures and equipment require documentation by reference only while non-standard test procedures or equipment should be documented in detail

Testing Procedures For Determining Static Soil Properties

- Tests of Ground Water or Surface Waters
  - Testing of ground water and surface water depends on the nature of potential problems identified at the site
  - Standard methods of testing water for physical, chemical, radioactive, and microbiological properties are described in Standard Methods for the Examination of Water and Wastewater (1999)

Testing Procedures For Determining Static Soil Properties

- Tests of Ground Water or Surface Waters
  - The standard methods include methods of testing polluted water, wastewaters, effluents, bottom sediments, and sludges
  - Standard testing methods should be used unless special problems are encountered that require modifications or alternative methods

Testing Procedures For Determining Dynamic Soil Properties

- Before dynamic tests are performed, the initial state of stress in the soil should be determined, and a series of static consolidated-drained and consolidated-undrained triaxial compression tests should be made to determine static strength

Testing Procedures For Determining Dynamic Soil Properties

- Dynamic testing program should include tests to determine
  - Soil parameters needed as input for reference analyses and soil structure interaction studies
  - Dynamic strength characteristics and liquefaction potential of soils
- Dynamic soils property testing includes Cyclic Triaxial Tests and Resonant Column Tests

Testing Procedures For Determining Dynamic Soil Properties

- Cyclic Triaxial Tests
  - Cyclic loading technique for investigating liquefaction resistance factors
  - Most common due to availability of equipment and ease of preparing undisturbed specimens
  - Lnability of the test to accurately represent field earthquake stresses and boundary conditions

Testing Procedures For Determining Soil Properties

- Cyclic Triaxial Tests
  - Laboratory-determined cyclic triaxial strengths are higher than those expected to produce equivalent effects in the field
    - not accurately modeling the stress conditions in situ
    - Need reduction adjustments of cyclic stress values obtained from triaxial tests
    - should be used only to establish parametric effects on cyclic strength behavior

Testing Procedures For Determining Soil Properties

- Cyclic Triaxial Tests
  - estimation of field cyclic test results may not be possible by universal application of sample factors, e.g., gradation, density, and soil type

Testing Procedures For Determining Soil Properties

- Resonant Column Tests
  - ASTM D 4015, "Standard Test Methods for Modulus and Damping of Soils by the Resonant-Column Method," describes testing procedures to determine the shear modulus, shear damping, rod modulus (Young's modulus), and rod damping for solid cylindrical specimens of soil in undisturbed and remolded conditions by vibration using the resonant column

Laboratory Testing Methods For Soil and Rock

Test Categories of Soils and Rock

Material	Soil Test Category
Soils	Index and Classification Tests
	Moisture-Density Relations
	Consolidation and Permeability
	Physical and Chemical Properties
	Shear Strength and Deformability
Rocks	Engineering Properties

Laboratory Testing Methods For Soil

Soil Test Category	Name of Test	Properties or Parameters Determined
Index and Classification of Soils	Gradation Analysis	Particle size distribution
	Percent fines	Percent of weight of material finer than No. 200 sieve
	Atterberg Limits	Liquid and plastic limit, plasticity index, shrinkage factor (limit)
	Specific Gravity	Specific gravity, apparent specific gravity, bulk unit weight sufficiently fine to eliminate internal voids in the intact rock
	Radiography	Qualitative test of sample quality
	Description of Soil and Rock	Description of soil from visual-manual examination

Laboratory Testing Methods For Soil

Soil Test Category	Name of Test	Properties or Parameters Determined
Moisture-Density Relations of Soil	Bulk Unit Weight	Bulk unit weight (bulk density)
	Water (Moisture) Content	Water content as a percent of dry weight
	Relative Density	Maximum and minimum density of cohesionless soils
	Compaction	Maximum dry unit weight of soil
Consolidation and Permeability of Soil	Consolidation	One-dimensional compressibility, permeability of cohesive Soil
	Permeability	Permeability

Laboratory Testing Methods For Soil

Soil Test Category	Name of Test	Properties or Parameters Determined
Physical and Chemical Properties of Soil	Mineralogy	Identification of minerals
	Organic Content	Organic and inorganic carbon content as percent of dry weight
	Soluble Salts	Concentration of soluble salts in soil pore water
	Erodibility Tests (Pinhole Test, Crumb Test, SCS Test, Cylinder Dispersion)	Significant in evaluation of potential erosion or piping.

Laboratory Testing Methods For Soil

Soil Test Category	Name of Test	Properties or Parameters Determined
Shear Strength and Deformability of Soil	Unconfined Compression	Strength of cohesive soil in uniaxial compression
	Direct Shear, Consolidated-drained	Cohesion and angle of internal friction under drained conditions
	Triaxial Compression , Unconsolidated-Undrained	Shear strength parameters; Cohesion and angle of internal friction for soils of low permeability
	Triaxial Compression, Consolidated-Drained	Shear strength parameters; Cohesion and angle of internal friction. For long-term loading conditions

Laboratory Testing Methods For Soil

Soil Test Category	Name of Test	Properties or Parameters Determined
Shear Strength and Deformability (Cont.) of Soil	Triaxial Compression, Consolidated-Undrained	Shear strength parameters; Cohesion and angle of internal friction for consolidated soil. With pressure measurements, cohesion and friction may be obtained
	Cyclic Triaxial	Local strain, modulus and damping
	Cyclic Simple Shear	Shear modulus and damping values and cyclic-strength of cohesive and cohesionless soils
	Resonant Column	Shear modulus and damping in cohesive and cohesionless soils

Testing Procedures For Determining Engineering Properties of Rock

- Common tests include

Porosity	Unconfined Compression
Permeability	Triaxial Compression
Seismic Velocity	Slate Durability
Direct Tensile Strength	Specific Gravity
Direct Shear	

Laboratory Testing Methods For Rocks

Rock Test Category	Name of Test	Properties or Parameters Determined
Engineering Properties of Rocks	Water Content	Water Content
	Specific Gravity	
	Porosity	Bulk unit weight, specific gravity, and total porosity (Melcher Method) or effective porosity (Simmons or Washburn-Bunting Method)
	Permeability	Permeability of intact rock
	Degradation Resistance	Percent of weight of rock greater than 3/4 in (19 mm)
	Seismic Velocity	Compressional and shear wave velocities in intact rock
	Direct Tensile Strength	Uniaxial tensile strength of intact rock

Laboratory Testing Methods For Rocks

Rock Test Category	Name of Test	Properties or Parameters Determined
Engineering Properties of Rocks (Cont..)	Splitting Tensile Strength ("Brazilian Test")	Indirect measure of tensile strength of intact rock
	Modulus of Rupture	Indirect measure of tensile strength of intact rock
	Unconfined Compression	Young's moduli and unconfined compression strength of intact rock
	Uniaxial Compression	Young's moduli, Possion ratio
	Triaxial Compression Undrained	Young's moduli, cohesion friction parameters of failure Envelope
	Triaxial Compression Without Pore Pressure Measurements	Young's moduli, cohesion friction Parameters

Laboratory Testing Methods For Rocks

Rock Test Category	Name of Test	Properties or Parameters Determined
Engineering Properties of Rocks (Cont..)	Triaxial Compression With Pore Pressure Measurements	Young's moduli, cohesion friction parameters of effective stress conditions
	Slake Durability	Index of resistance to Slaking
	Direct Shear	Shear strength

Completed Items of Overall Outline

3000. Site Investigation

- Objective and Scope Met
  - Present and discuss
    - Site investigation for foundations of nuclear power plants
    - Laboratory investigations and soil sampling of soils and rocks for engineering analysis and design of nuclear power plants