CHAPTER 2.0
PROJECT INITIATION

2.1 PROJECT TYPE

2.1.1 New Construction

In general there are two types of subsurface investigation that new construction may require; the first being a conceptual subsurface investigation, or route selection study, where the geotechnical engineer is asked by the designers to identify the best of several possible routes or locations for the proposed structures, or to evaluate foundation alternatives. This type of project generally does not require a detailed subsurface investigation. It is normally limited to geologic reconnaissance and some sampling, field identification of subsurface conditions to achieve generalized site characterization, and general observations such as the presence of solution cavities, organic deposits in low lying areas, and the depth of rock or competent soils, etc. Conceptual study investigations require limited laboratory testing and largely depend on the description of subsurface conditions from boring logs prepared by an experienced field engineer and/or geologist. Properly performed exploratory investigations, in cases where the designers have flexibility in locating the project to take advantage of favorable subsurface conditions, have the potential for resulting in substantial savings by avoiding problematic foundation conditions and costly construction methods.

The second and more common type of subsurface investigation is the detailed investigation to be performed for the purpose of detailed site characterization to be used for the design of the structures. Frequently, the design phase investigation is performed in two or more stages. The initial, or preliminary design, stage investigation is typically performed early in the design process prior to defining the proposed structure elements or the specific locations of foundations, embankments or earth retaining structures. Accordingly, the preliminary design investigation typically includes a limited number of borings and testing sufficient for defining the general stratigraphy, soil and rock characteristics, groundwater conditions, and other existing features of importance to foundation design. Subsequently, after the location of structure foundations and other design elements have been determined, a second, or final design, phase investigation is frequently performed to obtain site specific subsurface information at the final substructure locations for design purposes and to reduce the risk of unanticipated ground conditions during construction. Further investigation stages can be considered if there are significant design changes or if local subsurface anomalies warrant further study. When properly planned, this type of multi-phase investigation provides sufficient and timely subsurface information for each stage of design while limiting the risk and cost of unnecessary explorations.

Prior to planning and initiating the investigation, the geotechnical engineer needs to obtain from the designers the type, load and performance criteria, location, geometry and elevations of the proposed facilities. The locations and dimensions of cuts and fills, embankments, retaining structures, and substructure elements should be identified as accurately as practicable. Bridge locations, approaches, and types of bridge construction should be provided in sufficient detail to allow a determination of the location, depth, type and number of borings to be performed. In cases where the investigation is being done for buildings, such as toll plazas, tourist information centers, and recreational or rest facilities, the designers should provide the location and the footprint of the building, the location of columns, if any, and building or column loads.

2.1.2 Rehabilitation Projects

The detail required for the subsurface investigation of rehabilitation projects (Figure 2-1) depends on a number of variables, including:

- The condition of the facility to be rehabilitated.
- If the facility is distressed, the nature of distress (pavement failure, deep seated failures, structure settlement, slides, etc.)
- Whether the facility will be returned to its original, as-built, condition or will be upgraded, say adding another lane to a pavement or a bridge.
- If facilities will be upgraded, the proposed geometry, location, loadings and structure changes (i.e. culvert to bridge).
- The required design life of the rehabilitated facility.

The above information should be obtained to aid in planning an appropriate investigation program.

2.1.3 Contaminated Sites

The geotechnical engineer occasionally must perform subsurface investigations at sites with contaminated soils or groundwater. Contamination may be of a non-hazardous or hazardous nature. Sampling and handling of contaminated samples is a complicated topic which is beyond the scope of this course. However, it is necessary for all involved in geotechnical investigations to be aware of the salient points of these procedures. The US Environmental Protection Agency (EPA) document number 625/12-91/002 titled "Description and Sampling of Contaminated Soils - A Field Pocket Guide" contains guidelines and background information, and a list of useful references on the topic.

When an investigation is to be performed, acquisition records for newly obtained right-of-way (ROW) will indicate the most recent land use for the area. Furthermore, the environmental section of the agency will most probably have developed environmental impact statements (EIS) and will have identified contaminated areas and the type of contamination. The ROW and environmental sections of the agency should be routinely contacted for this information at the investigation planning stage. On rehabilitation projects where the only planned activities will be on the existing ROW the information available may vary from very complete to none. Old gravel or compacted soil roads have occasionally been constructed using waste products as dust palliatives, and where these roads were later covered with, say bituminous hot mix concrete, the subsurface exploration may encounter layers of contaminated soils. Also, there may be a risk of contaminant migration through groundwater movement from off-site sources.

Some signs of possible contamination are:

- Prior land use (e.g. landfills, gas stations, etc.).
- Stained soil or rock.
- Apparent lack of vegetation or presence of dead vegetation and trees.

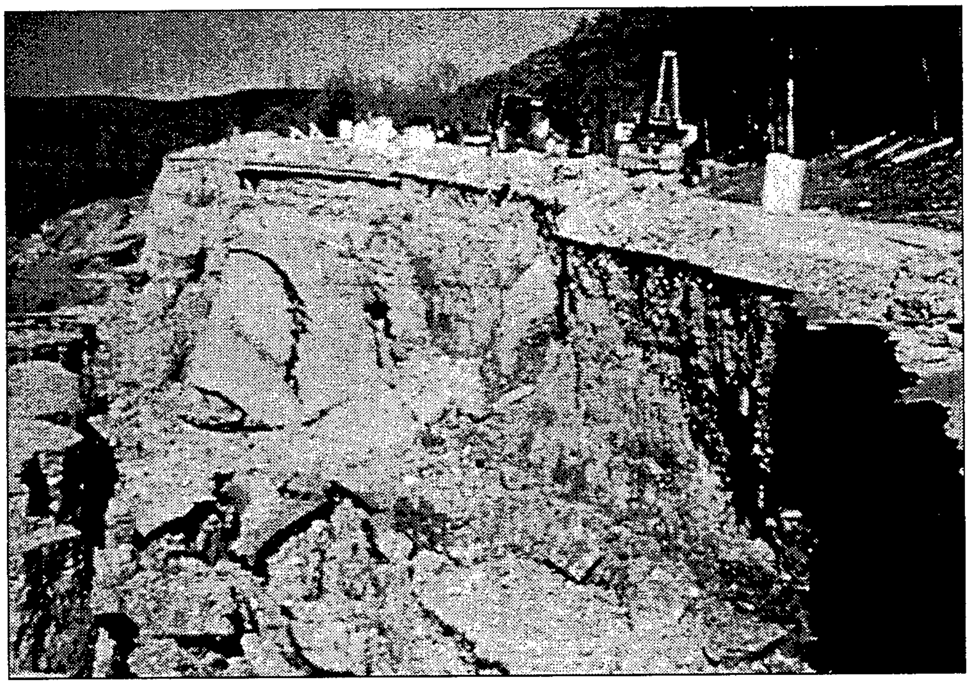


Figure 2-1: Embankment Slope Failure.

- Odors (It should be noted that highly organic soils often will have a rotten egg odor which should not be construed as evidence of contamination. However, this odor may also be indicative of highly toxic hydrogen sulfide. Drilling crews should be instructed as such).

- Presence of liquids other than groundwater or pore water.

- Signs of prior ground fires (at landfill sites). Established landfills will emit methane gas which is colorless and odorless, and in high concentrations in the presence of sparks or fire it will explode. At low concentrations under certain conditions (i.e. lightning) it will burn. Areas containing natural organic deposits also produce and emit methane gas.

- Presence of visible elemental metals (i.e., mercury).

- Low (<2.5) or High (>12.5) pH.

Easy to use field testing equipment such as air quality monitoring devices, pH measurement kits, photoionization detectors, etc. can be used to perform preliminary tests to identify the presence of some contaminants.

EPA documents provide guidelines and protocols for sampling, packaging, and transporting of contaminated soils as well as for field and laboratory testing. Additionally, many states have developed their own protocols, some of which are stricter than the ones developed by EPA. These documents need to be consulted prior to any attempt to sample or test suspect materials.

In most environmental applications, the US Department of Agriculture Soil Conservation Service (SCS) taxonomy rather than geotechnical engineering classifications are applied. A complete reference work to SCS soil taxonomy is "The Agricultural Handbook No. 18" published by the Soil Conservation Service, Washington, D.C. Copies of this handbook can be obtained through state or regional offices of SCS.

2.2 EXISTING DATA SOURCES

The first step in the investigation process is the review of existing data. There are a number of very helpful sources of data that can and should be used in planning subsurface investigations. Review of this information can often minimize surprises in the field, assist in determining boring locations and depths, and provide very valuable geologic and historical information which may have to be included in the geotechnical report.

Following is a partial list of useful sources of geological, historical and topographic information. Specific information available from these and other reference sources is presented in the U.S. Navy Design Manual 7.1 (1982).

- Prior subsurface investigations (historical data) at or near the project site.

- Prior construction and records of structural performance problems at the site (i.e. pile length/capacity problems, rock slides, excessive seepage, unpredicted settlement, etc.). Some of this information may only be available in anecdotal forms. The more serious ones should be investigated, documented if possible, and evaluated by the engineer.

- U.S. Geological Survey maps, reports and publications.

- State Geological Survey maps, reports and publications.

- State flood zone maps prepared by state or US Geological survey or FEMA can be obtained from local or regional offices of these agencies.

- Department of Agriculture SCS Soil Maps - A list of published soil surveys is issued annually. It should be noted that these are well researched maps but they only provide detailed information for surficial deposits. They may show frost penetration depths, drainage characteristics, etc.

- Geological Societies (Association of Engineering Geologists, Association of American State Geologists).

- Local university libraries and geology departments.

- Public Libraries and the Library of Congress.

- Earthquake data, seismicity, fault maps, etc. prepared by
  - U.S. Geological Survey
  - Earthquake Engineering Research Center (EERC), University of California, Berkeley.
  - Earthquake Engineering Research Institute (EERI), Stanford University
  - National Earthquake Engineering Research Program (NEERP), Washington, D.C.
  - National Center of Earthquake Engineering Research (NCEER), Rochester, N.Y.
  - Advanced Technology Council (ATC), Redwood City, California

- Worldwide National Earth-Science Agencies (USGS Circular 716, 1975).

- U.S. Bureau of Mines

- State and County Road Maps

- Aerial Photographs (USGS, US SCS, Earth Resource Observation System).

- Remote Sensing Images (LANDSAT, Skylab, NASA).

- Site Plans showing location of ditches, driveways, culverts, utilities, etc.

- Maps of streams, rivers and other water bodies to be crossed by bridges, culverts, etc., including bathimetric data.

The majority of the above information can be obtained from commercial sources (i.e. duplicating services) or U.S. and state government local or regional offices. Specific sources (toll free phone numbers, addresses etc.) for flood and geologic maps, aerial photographs, USDA soil surveys, can very quickly identified through the Internet.

2.3 SITE VISIT/PLAN-IN-HAND

It is imperative that the geotechnical engineer, and if possible the project design engineer, conducts a reconnaissance visit to the project site to develop an appreciation of the geotechnical, topographic, and geological features of the site and become knowledgeable of access and working conditions. The plan-in-hand site visit is a good opportunity to learn about:

- Design and construction plans
- General site conditions
- Geologic reconnaissance
- The geomorphology
- Access restrictions for equipment
- Traffic control requirements during field investigations
- Location of underground and overhead utilities
- Type and condition of existing facilities (i.e. pavements, bridges, etc.)
- Adjacent land use (schools, churches, research facilities, etc.)
- Restrictions on working hours
- Right-of-way constraints
- Environmental issues
- Escarpments, outcrops, erosion features, and surface settlement
- Flood levels
- Water traffic and access to water boring sites
- Benchmarks and other reference points to aid in the location of boreholes
- Equipment storage areas/security

2.4 COMMUNICATION WITH DESIGNERS/PROJECT MANAGERS

The geotechnical engineer should have periodic discussions with the field inspector while the investigation program is ongoing. He or she should notify the project or the design engineer of any unusual conditions or difficulties encountered, and any changes made in the investigation program or schedule. The frequency of these communications depends on the critical nature of the project, and on the nature and seriousness of the problems encountered.

Figure 2-2 illustrates a useful Field Instructions form which can be used to clearly communicate the general requirements of the investigation program to all field personnel, and to present useful contact phone numbers.

PROJECT INFORMATION: Project No.:____________________

Name:____

Location:____

Site Contact (Project Engineer):________________________Phone:____________________

Utility Contact:________________________________Reference No.:____________________

Right of Entry Contact:____

Other Contact (specify): ____________________________Home Phone: ____________________

Estimated Time:____

BORING INFORMATION

Boring No.	Depth	Drilling Sequence	Sampling	Remarks (piezometers, water levels, etc.)

Health and Safety Provisions: Special Plan:______________________________

Sample type, frequency:____

Disposal of Cuttings/Drill Fluids:____________________________________

Boring Closure: Cuttings: ________________________Grout:____________________

Remarks:____

Figure 2-2: Form for Field Instructions.

2.5 SUBSURFACE EXPLORATION PLANNING

Following the collection and evaluation of available information from the above sources, the geotechnical engineer is ready to plan the field exploration program. The field exploration methods, sampling requirements, and types and frequency of field tests to be performed will be determined based on the existing subsurface information, project design requirements, the availability of equipment, and local practice. The geotechnical engineer should develop the overall investigation plan to enable him or her to obtain the data needed to define subsurface conditions and perform engineering analyses and design. A geologist can often provide valuable input regarding the type, age and depositional environment of the geologic formations present at the site for use in planning and interpreting the site conditions.

Frequently, the investigation program must be modified after initiating the field work because of site access constraints or to address variations in subsurface conditions identified as the work proceeds. To assure that the necessary and appropriate modifications are made to the investigation program, it is particularly important that the field inspector (preferably a geotechnical engineer or geologist) be thoroughly briefed in advance regarding the nature of the project, the purpose of the investigation, the sampling and testing requirements, and the anticipated subsurface conditions. The field inspector is responsible for verifying that the work is performed in accordance with the program plan, for communicating the progress of the work to the project geotechnical engineer, and for immediately informing the geotechnical engineer of any unusual subsurface conditions or required changes to the field investigation. Table 2-1 lists the general guidelines to be followed by the geotechnical field inspectors.

2.5.1 Types of Investigation

Generally, there are five types of field subsurface investigation methods:

1. Disturbed sampling
2. Undisturbed sampling
3. In situ investigation
4. Geophysical investigation
5. Remote sensing

Disturbed Sampling

Disturbed samples are generally obtained to determine the soil type, gradation, classification, consistency, density, presence of contaminants, stratification, etc. The methods for obtaining disturbed samples vary from hand excavating of materials with picks and shovels to using truck mounted augers and other rotary drilling techniques. These samples are considered "disturbed" since the sampling process modifies their natural structure.

Undisturbed Sampling

Undisturbed samples are used to determine the in place strength, compressibility (settlement), natural moisture content, unit weight, permeability, discontinuities, fractures and fissures of subsurface deposits. Even though such samples are designated as "undisturbed," in reality they are disturbed to varying degrees. The degree of disturbance depends on the type of subsurface materials, type and condition of the sampling equipment used, the skill of the drillers, and the storage and transportation methods used. **As will be discussed later, serious and costly inaccuracies may be introduced into the design if proper protocol and care is not exercised during recovery, transporting or storing of the samples.**

TABLE 2-1
GENERAL GUIDELINES FOR GEOTECHNICAL FIELD INSPECTORS

Thoroughly comprehend purpose of field work (i.e. to characterize the site for the intended engineering applications.)

- Be thoroughly familiar with the scope of the project, technical specifications and pay items (keep a copy of the boring location plan and specifications in the field).
- Be familiar with site and access conditions and any restrictions.
- Review existing subsurface and geologic information before leaving the office.
- Constantly review the field data obtained as it relates to the purpose of the investigation.
- Maintain daily contact with the geotechnical project engineer; brief him/her regarding work progress, conditions encountered, problems, etc.
- Fill out forms regularly (obtain sufficient supply of forms, envelopes, stamps if needed before going to the field). Typical forms may include:
  - Daily field memos
  - Logs of borings, test pits, well installation, etc.
  - Subcontract expense report - fill out daily, co-sign with driller
- Closely observe the driller's work at all times, paying particular attention to:
  - Current depth (measure length of rods and samplers)
  - Drilling and sampling procedures
  - Any irregularities, loss of water, drop of rods, etc.
  - Count the SPT blows and blows on casing
  - Measure depth to groundwater and note degree of sample moisture
- Do not hesitate to question the driller or direct him to follow the specifications
- Classify soil and rock samples; put soil samples in jars and label them; make sure rock cores are properly boxed, photographed, stored and protected.
- Verify that undisturbed samples are properly taken, handled, sealed, labeled and transported.
- Do not divulge information to anyone unless cleared by the geotechnical project engineer or the project manager.
- Bring necessary tools to job (see Table 2-4).
- Take some extra jars of soil samples back to the office for future reference.
- Do not hesitate to stop work and call the geotechnical project engineer if you are in doubt or if problems are encountered.
- **ALWAYS REMEMBER THAT THE FIELD DATA ARE THE BASIS OF ALL SUBSEQUENT ENGINEERING DECISIONS AND AS SUCH ARE OF PARAMOUNT IMPORTANCE.**

In situ Investigation

In situ testing and geophysical methods can be used to supplement the above types of borings. Some in situ testing devices, such as electronic cone penetrometer tests (CPT), besides being able to provide accurate data on subsurface soils by reducing disturbance associated with sampling and handling of soil samples, they can do so on a real time basis. Certain characteristics such as strength and skin friction as well as piezometric data can be obtained as the CPT progresses in the field. Since all measurements are done during the field operations and there are no laboratory samples to be tested, considerable time and cost savings may result from the use of in situ methods. In situ methods can be particularly effective when they are used in conjunction with conventional sampling to reduce the cost and the time for field work. These tests provide a host of subsurface information in addition to developing more refined correlations between conventional sampling, testing and in situ soil parameters.

Geophysical Investigation

Some of the more commonly used geophysical tests are resistivity, ground penetrating radar, seismic reflection, cross hole seismic, and seismic cone penetrometer tests. Such tests are particularly effective in establishing ground stratigraphy, locating sudden changes in underground formations, determining in situ dynamic properties of soils, and locating underground cavities in karst formations, or identifying underground obstructions.

Remote Sensing

Remote sensing data can effectively be used to identify terrain conditions, geologic formations, escarpments and surface reflection of faults, buried stream beds, site access conditions and general soil and rock formations. Remote sensing data from satellites (i.e LANDSAT data available from NASA), aerial photographs available from the US or state Geological services, U.S. Corps Of Engineers, commercial aerial mapping service organizations can be easily obtained, State DOTs use aerial photographs for right-of-way surveys and road and bridge alignments, and they can make them available for use by the geotechnical engineers.

The geotechnical engineer needs to be familiar with these sampling, investigation and testing techniques, as well as their limitations and capabilities before selecting their use on any project. The details of these investigation methods will be presented in subsequent chapters of this module.

2.5.2 Frequency and Depth of Borings

The location and frequency of sampling depends on the type and critical nature of the structure to be built, the soil and rock formations, the known variability in stratification, and the loads to be imposed on the foundation soils. While the rehabilitation of an existing pavement may require 4 m deep borings only at locations showing signs of distress, the design and construction of a major bridge may require borings often in excess of 30 m.

Table 2-2 provides guidelines for selecting minimum boring depths, frequency and spacing for various geotechnical features. Frequently, it may be necessary or desirable to extend borings beyond the minimum depths to better define the geologic setting at a project site, to determine the depth and engineering characteristics of soft underlying soil strata, or to assure that sufficient information is obtained for cases when the structure requirements are not clearly defined at the time of drilling. **Where borings are drilled to rock, it is generally recommended that a minimum 1.5 m length of rock core be obtained to verify**

TABLE 2-2
MINIMUM REQUIREMENTS FOR BORING DEPTHS

Areas of Investigation	Boring Depth
Bridge Foundations* Highway Bridges	
1. Spread Footings	For isolated footings of length L_f and width $\leq 2B_f$, where $L_f \leq 2B_f$, borings shall extend a minimum of two footing widths below the bearing level. For isolated footings where $L_f \geq 5B_f$, borings shall extend a minimum of four footing widths below the bearing level. For $2B_f \leq L_f \leq 5B_f$, minimum boring length shall be determined by linear interpolation between depths of $2B_f$ and $5B_f$ below the bearing level.
2. Deep Foundations	In soil, borings shall extend below the anticipated pile or shaft tip elevation a minimum of 6 m, or a minimum of two times the maximum pile group dimension, whichever is deeper. For piles bearing on rock, a minimum of 3 m of rock core shall be obtained at each boring location to verify that the boring has not terminated on a boulder. For shafts supported on or extending into rock, a minimum of 3 m of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.
Retaining Walls	Extend borings to depth below final ground line between 0.75 and 1.5 times the height of the wall. Where stratification indicates possible deep stability or settlement problem, borings should extend to hard stratum. For deep foundations use criteria presented above for bridge foundations.
Roadways	Extend borings a minimum of 2 m below the proposed subgrade level.
Cuts	Borings should extend a minimum of 5 m below the anticipated depth of the cut at the ditch line. Borings depths should be increased in locations where base stability is a concern due to the presence of soft soils, or in locations where the base of the cut is below groundwater level to determine the depth of the underlying pervious strata.
Embankments	Extend borings a minimum depth equal to twice the embankment height unless a hard stratum is encountered above this depth. Where soft strata are encountered which may present stability or settlement concerns the borings should extend to hard material.
Culverts	Use criteria presented above for embankments.

*From AASHTO Standard Specifications for Design of Highway Bridges

that the boring has indeed reached bedrock and not terminated on the surface of a boulder.

Where structures are to be founded directly on rock, the length of rock core should be not less than 3 m, and extended further if the use of socketed piles or drilled shafts are anticipated. Selection of boring depths at river and stream crossings must consider the potential scour depth of the stream bed.

The frequency and spacing of borings will depend on the anticipated variation in subsurface conditions, the type of facility to be designed, and the phase of the investigation being performed. For conceptual design or route selection studies, very wide boring spacing (up to 300 m, or more) may be acceptable particularly in areas of generally uniform or simple subsurface conditions. For preliminary design purposes a closer spacing is generally necessary, but the number of borings would be limited to that necessary for making basic design decisions. For final design, however, relatively close spacings of borings may be required as suggested in Table 2-3.

Subsurface investigation programs, regardless to how well they may be planned, must be flexible to adjust to variations in subsurface conditions encountered during drilling. The project geotechnical engineer should at all times be available to confer with the field inspector. On critical projects, the geotechnical engineer should be present during the field investigation. He/she should also establish communication with the design engineer to discuss unusual field observations and changes to be made in the investigation plans.

2.5.3 Boring Locations and Elevations

It is generally recommended that a licensed surveyor be used to establish all planned drilling locations and elevations. For cases where a surveyor cannot be provided, the field inspector has the responsibility to locate the borings and to determine ground surface elevations at an accuracy appropriate to the project needs. Boring locations should be taped from known site features to an accuracy of about 1.0 m for most projects. When a topographic survey is provided, boring elevations can be established by interpolation between contours. This method of establishing boring elevations is commonly acceptable, but the field inspector must recognize that the elevation measurement is sensitive to the horizontal position of the boring. Where contour intervals change rapidly the boring elevations should be determined by optical survey.

Sometimes a bench mark (BM) is indicated on the site plans or topographic survey. If a BM is not indicated, a temporary bench mark (TBM) should be established on some permanent feature (manhole, intersection of two streets, fire hydrant, existing building, etc.). A TBM should be a feature that will remain intact during the future construction operation. Typically, the TBM is set up as an arbitrary elevation (unless the local ground elevation is uniform). Field inspectors should always indicate which TBM was used on the site plan.

An engineer's level may be used to determine elevations. The level survey should be closed to confirm the accuracy of the survey. Elevations should be reported on the logs to the nearest tenth of a meter unless other directions are received from the designers. In all instances, the elevation datum must be identified and recorded. Throughout the boring program the datum selected should remain unchanged.

2.5.4 Equipment

A list of equipment commonly needed for field explorations is presented in Table 2-4.

TABLE 2-3
GUIDELINES FOR BORING LAYOUT*

Geotechnical Features	Boring Layout
Bridge Foundations	For piers or abutments over 30 m wide, provide a minimum of two borings. For piers or abutments less than 30 m wide, provide a minimum of one boring. Additional borings should be provided in areas of erratic subsurface conditions.
Retaining Walls	A minimum of one boring should be performed for each retaining wall. For retaining walls more than 30 m in length, the spacing between borings should be no greater than 60 m. Additional borings inboard and outboard of the wall line to define conditions at the toe of the wall and in the zone behind the wall to estimate lateral loads and anchorage capacities should be considered.
Roadways	The spacing of borings along the roadway alignment generally should not exceed 60 m. The spacing and location of the borings should be selected considering the geologic complexity and soil/rock strata continuity within the project area, with the objective of defining the vertical and horizontal boundaries of distinct soil and rock units within the project limits.
Cuts	A minimum of one boring should be performed for each cut slope. For cuts more than 60 m in length, the spacing between borings along the length of the cut should generally be between 60 and 120 m. At critical locations and high cuts, provide a minimum of three borings in the transverse direction to define the existing geological conditions for stability analyses. For an active slide, place at least one boring upslope of the sliding area.
Embankments	Use criteria presented above for Cuts.
Culverts	A minimum of one boring at each major culvert. Additional borings should be provided for long culverts or in areas of erratic subsurface conditions.

*Also see FHWA Geotechnical Checklist and Guidelines; FHWA-ED-88-053

TABLE 2-4
LIST OF EQUIPMENT FOR FIELD EXPLORATIONS

Paperwork/Forms	Site Plan Technical specifications Field Instructions Sheet(s) Daily field memorandum forms Blank boring log forms Forms for special tests (vane shear, permeability tests, etc.) Blank sample labels or white tape Copies of required permits Field book (moisture proof) Health and Safety plan Field Manuals Subcontractor expense forms
Sampling Equipment	Samplers and blank tubes etc. Knife (to trim samples) Folding rule (measured in 1 cm increments) 25 m tape with a flat-bottomed float attached to its end so that it can also be used for water level measurements Hand level (in some instances, an engineer's level is needed) Rags Jars and core boxes Sample boxes for shipping (if needed) Buckets (empty) with lid if bulk samples required Half-round file Wire brush
Safety/Personal Equipment	Hard hat Safety boots Safety glasses (when working with hammer or chisel) Rubber boots (in some instances) Rain gear (in some instances) Work gloves
Miscellaneous Equipment	Clipboard Pencils, felt markers, grease pencils Scale and straight edge Watch Calculator Camera Compass Wash bottle or test tube Pocket Penetrometer and/or Torvane Communication Equipment (two-way radio, cellular phone)

2.5.5 Personnel and Personal Behavior

The field crew is a visible link to the public. The public's perception of the reputation and credibility of the agency represented by the field crew may be determined by the appearance and behavior of the personnel and field equipment. It is the drilling supervisor's duty to maintain a positive image of field exploration activities, including the appearance of equipment and personnel and the respectful behavior of all personnel. In addition, the drilling supervisor is responsible for maintaining the safety of drilling operations and related work, and for the personal safety of all field personnel and the public. The designated Health and Safety Officer is responsible for verifying compliance of all field personnel with established health and safety procedures related to contaminated soils or groundwater. Appendix A presents typical safety guidelines for drilling into soil and rock and health and safety procedures for entry into borings.

The field inspector may occasionally be asked about site activities. The field inspector should always identify the questioner. It is generally appropriate policy not to provide any detailed project-related information, since at that stage the project is normally not finalized, there may still be on going discussions, negotiations, right-of-way acquisitions and even litigation. An innocent statement or a statement based on one's perception of the project details may result in misunderstandings or potentially serious problems. In these situations it is best to refer questions to a designated officer of the agency familiar with all aspects of the project.

2.5.6 Plans and Specifications

Each subsurface investigation program must include a location plan and technical specifications to define and communicate the work to be performed.

The project location plan(s) should include as a minimum: a project location map; general surface features such as existing roadways, streams, structures, and vegetation; north arrow and selected coordinate grid points; ground surface contours at an appropriate elevation interval; and locations of proposed structures and alignment of proposed roadways, including ramps. On this plan or plans the proposed boring, piezometer, and in situ test hole locations; and a table which presents the proposed depth of each boring and in situ test hole, and the required depths for piezometer screens should be shown.

The technical specifications should clearly describe the work to be performed including the materials, equipment and procedures to be used for drilling and sampling, for performing in situ tests, and for installing piezometers. In addition, it is particularly important that the specifications clearly define the method of measurement and the payment provisions for all work items.

2.6 STANDARDS AND GUIDELINES

Field exploration by borings should be guided by local practice, by applicable FHWA and state DOTs procedures, and by the AASHTO and ASTM standards listed in Table 2-5.

Current copies of these standards and manuals should be maintained in the engineer's office for ready reference. The geotechnical engineer and field inspector should be thoroughly familiar with the contents of these documents, and should consult them whenever unusual subsurface situations arise during the field investigation. The standard procedures should always be followed; improvisation of investigative techniques may result in erroneous or misleading results which may have serious consequences on the interpretation of the field data.

TABLE 2-5
FREQUENTLY USED AASHTO AND ASTM STANDARDS FOR FIELD INVESTIGATIONS

Standard		Title
AASHTO	ASTM	
M 146	C 294	Descriptive Nomenclature for Constituents of Natural Mineral Aggregates
T 86	D 420	Guide for Investigating and Sampling Soil and Rock
-	D 1194	Test Method for Bearing Capacity of Soil for Static Load on Spread Footings
-	D 1195	Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
-	D 1196	Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
T 203	D 1452	Practice for Soil Investigation and Sampling by Auger Borings
T 206	D 1586	Method for Penetration Test and Split-Barrel Sampling of Soils
T 207	D 1587	Practice for Thin-Walled Tube Sampling of Soils
T 225	D 2113	Practice for Diamond Core Drilling for Site Investigation
M 145	D 2487	Test Method for Classification of Soils for Engineering Purposes
-	D 2488	Practice for Description and Identification of Soils (Visual-Manual Procedure)
T 223	D 2573	Test Method for Field Vane Shear Test in Cohesive Soil
-	D 3441	Test Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Test of Soils
-	D 3550	Practice for Ring-Lined Barrel Sampling of Soils
-	D 4220	Practice for Preserving and Transporting Soil Samples
-	D 4544	Practice for Estimating Peat Deposit Thickness
-	D 4719	Test Method for Pressuremeter Testing in Soils
-	D 4750	Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)
-	D 5079	Practices for Preserving and Transporting Rock Core Samples
-	D 5092	Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers

CHAPTER 3.0
DRILLING AND SAMPLING OF SOIL AND ROCK

This chapter describes some of the equipment and procedures commonly used for the drilling and sampling of soil and rock. The methods addressed in this chapter are typically used to retrieve soil samples and rock cores for visual examination and laboratory testing. Chapter 5 discusses in situ testing methods which are often included in subsurface investigation programs and are performed in conjunction with conventional drilling and sampling operations.

3.1 SOIL EXPLORATION

3.1.1 Soil Drilling

A wide variety of equipment (Appendix B - Manufacturers and Distributors of Soil Sampling Equipment) is generally available to perform borings and to obtain soil samples. The method used to advance the boring should be compatible with the soil and groundwater conditions to assure that soil samples of suitable quality are obtained. Particular care should be exercised to properly remove all slough or loose soil from the boring before sampling. Below the groundwater level, drilling fluids are often needed in soft soils or cohesionless soils to stabilize the sidewalls and bottom of the boring. Without stabilization, the bottom of the boring may heave or the sidewalls may contract, either disturbing the soil prior to sampling or preventing the sampler from reaching the bottom of the boring. In most geotechnical explorations, borings are usually advanced with 102 mm or 152 mm diameter solid-stem augers, 57 mm to 152 mm inside diameter hollow-stem augers, or rotary wash boring methods using a 60 mm to 130 mm nominal diameter drill bit. Figure 3-1 illustrates the drill bits commonly used in North American practice.

Continuous Flight Augers

Continuous-flight (solid-stem) auger drilling is generally limited to stiff cohesive soils where the boring walls are stable for the entire depth of the boring. Figure 3-2 illustrates how continuous flight augers are used with an auger drill. A drill bit is attached to the leading section of flight to cut the soil. The flights act as a screw conveyor, bringing cuttings to the top of the hole. As the auger drills into the earth, additional auger sections are added until the required depth is reached.

Due to their limited application, continuous flight augers are generally not suitable for use in investigations requiring soil sampling. When used, careful observation of the resistance to penetration and the vibrations or "chatter" of the drilling bit can provide valuable data for interpretation of the subsurface conditions. Clay, or "fishtail", drill bits are commonly used in stiff clay formations. Carbide-tipped "finger" bits are commonly used where hard clay formations or interbedded rock or cemented layers are encountered. Since finger bits commonly leave a much larger amount of loose soil, called slough, at the bottom of the hole, they should only be used when necessary. It is often desirable to twist the continuous-flight augers into the ground with rapid advancement and to withdraw the augers without rotation, often termed "dead-stick withdrawal", to maintain the cuttings on the auger flights with minimum mixing. This drilling method aids visual identification of changes in the soil formations. In all instances, the cuttings and the reaction of the drilling equipment should be regularly monitored to identify stratification changes between sample locations.

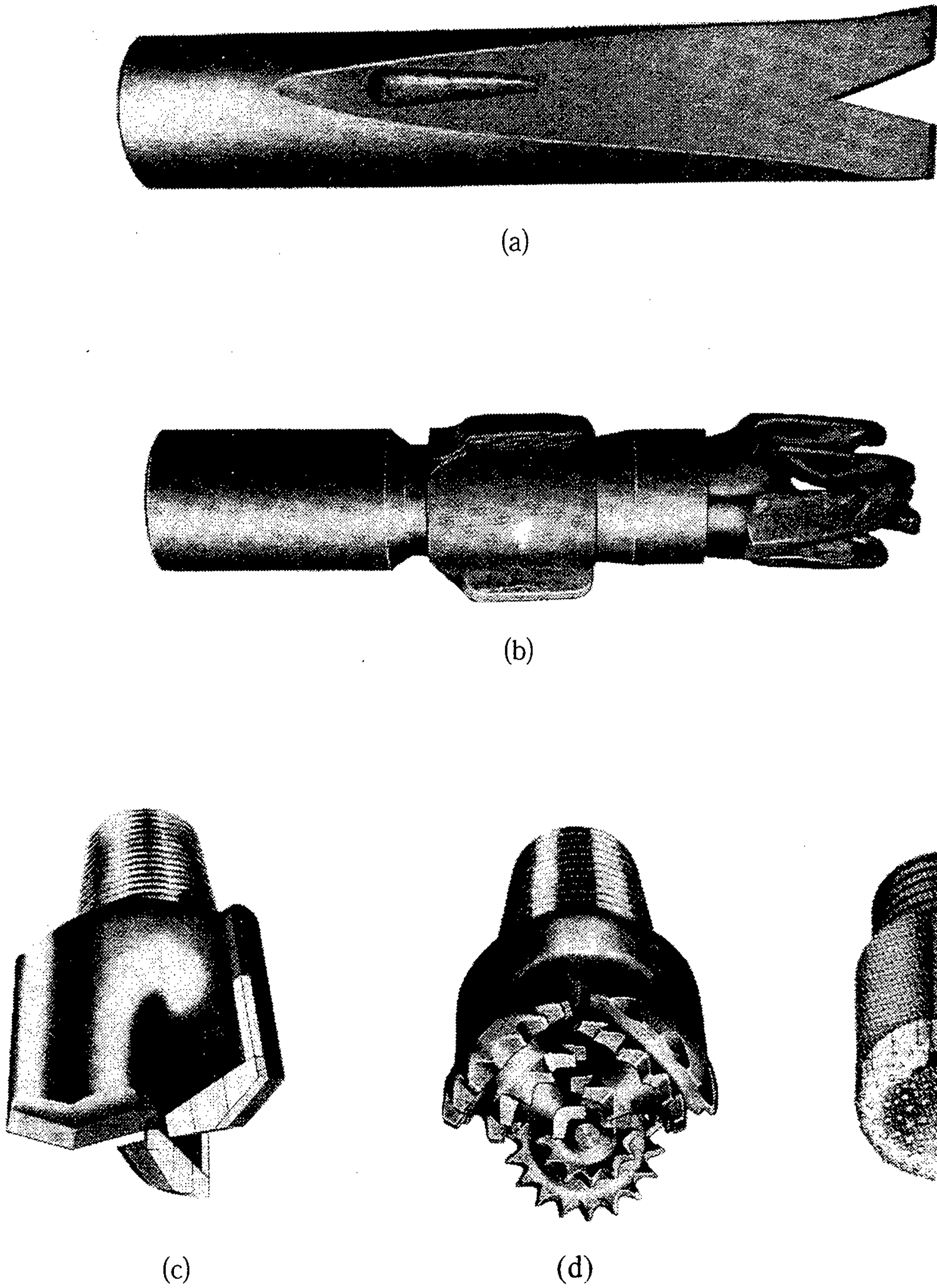


Figure 3-1: Drill Bits Commonly Used in North American Practice. (a) Fishtail Bit, (b) Hawthorne Replaceable-Blade Drag Bit, (c) Carbide Insert Drag Bit, (d) Tricone Bit, and (e) Diamond Plug. (Courtesy of Sprague & Henwood, Inc.)

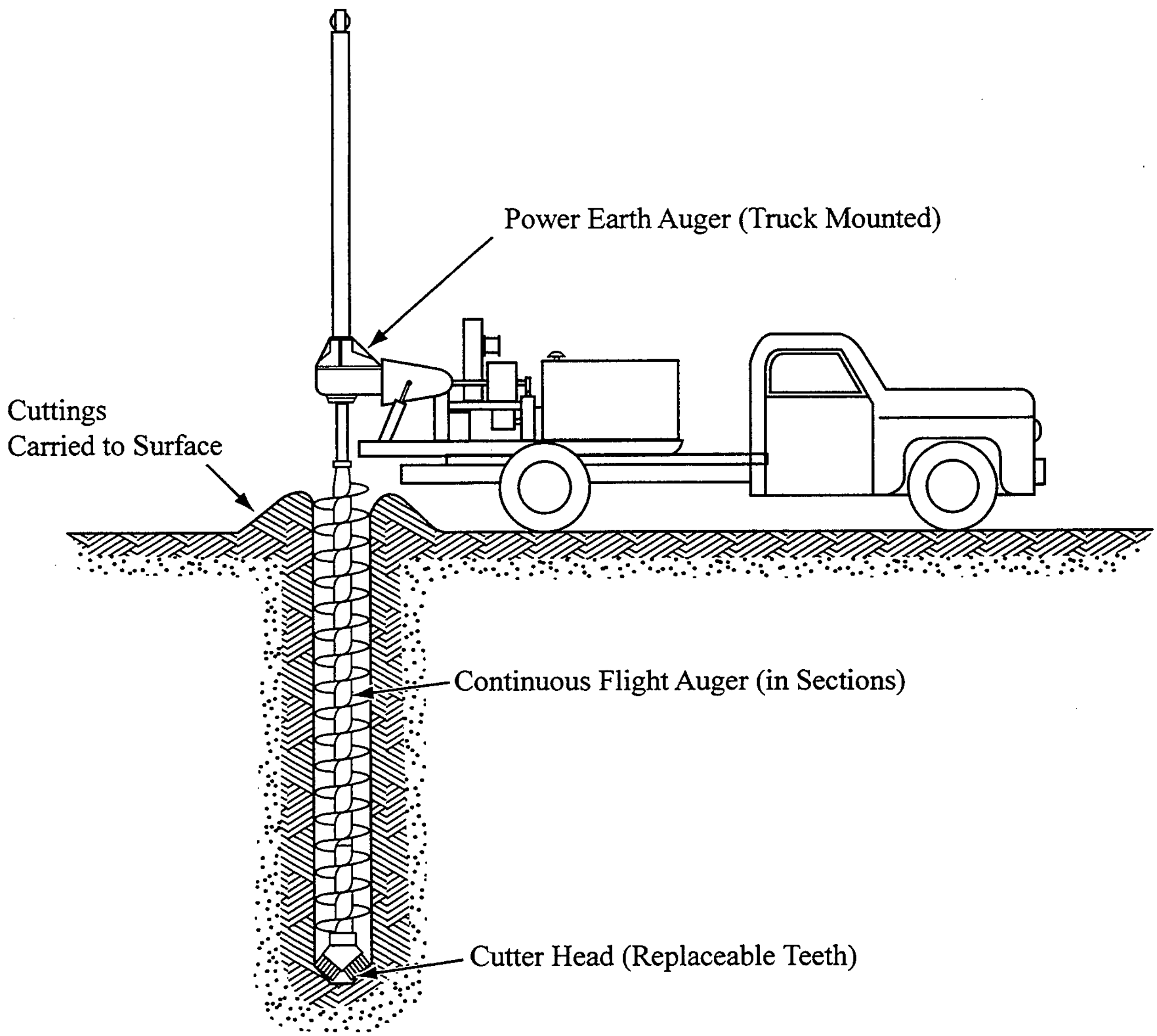


Figure 3-2: Typical Continuous Flight Auger Set-up. (Acker, 1974)

Hollow-Stem Augers

In general appearance hollow stem augers are very similar to the continuous flight auger except, as the name suggests, it has a large hollow center. Figure 3-3a shows the various parts of a hollow stem auger. Table 3-1 presents dimensions of hollow-stem augers available on the market. When the hole is being advanced, a center stem and plug are inserted into the hollow center of the auger. The center plug with a drag bit attached and located in the face of the cutter head aids in the advancement of the hole and also prevents soil cuttings from entering the hollow-stem auger. The center stem consists of rods that connect at the bottom of the plug or bit insert and at the top to a drive adapter to ensure that the center stem and bit rotate with the augers. Most drillers prefer to advance the boring without the center plug, allowing a natural "plug" of compacted cuttings to form at the bit and thus avoiding the need to remove and replace the bit and drill rods at each sample attempt. Since the extent of this plug is difficult to control, this practice is not recommended.

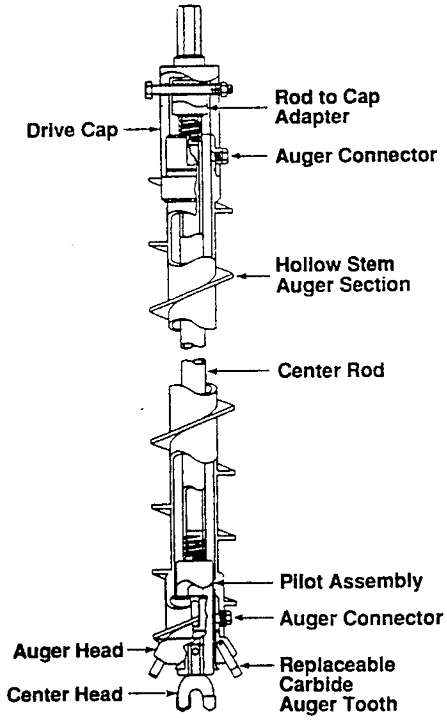
Once the augers have advanced the hole to the desired sample depth, the stem and plug are removed. A sampler may then be lowered through the hollow stem to sample the soil at the bottom of the hole. If part of the augers have been seated into rock, then the standard core barrels can be used.

Hollow-stem auger methods are commonly used in cohesive soils or in granular soil formations above the groundwater level, where the boring walls may be unstable. The augers form a temporary casing to allow sampling of the "undisturbed soil" below the bit. The cuttings produced from this drilling method have limited use for visual observation purposes (see Figure 3-3b). As the boring is advanced to greater depths a considerable delay may occur before the soil cuttings appear at the ground surface. The field supervisor must be aware of these limitations in identification of soil conditions between sample locations.

Significant problems can occur where hollow-stem augers are used to sample soils below the groundwater level. The unbalanced water pressure acting against the soil at the bottom of the boring can significantly disturb the soil, particularly in granular soils or soft clays. Often the soils will heave and plug the auger, preventing the sampler from reaching the bottom of the boring. Where heave or disturbance occurs, the penetration resistance to the driven sampler can be significantly reduced. For these reasons, and others, it is considered advisable to halt the use of hollow-stem augers at the groundwater level and to convert to rotary wash boring methods.

TABLE 3-1
DIMENSIONS OF TYPICAL HOLLOW-STEM AUGERS
(Central Mine Equipment Company)

Inside Diameter of Hollow Stem (mm)	Outside Diameter of Flighting (mm)	Cutting Diameter of Auger Head (mm)
57	143	159
70	156	171
83	168	184
95	181	197
108	194	210
159	244	260
210	295	318



(a)

(b)

Figure 3-3: (a) Hollow-Stem Auger (ASTM 4700), (b) Cuttings from a Saturated Soil During Hollow-Stem Augering.

Bucket Auger Borings

Bucket auger drills are used where it is desirable to remove and/or obtain large volumes of disturbed soil samples or to enter the boring to make observations and measurements, such as for projects where slope stability is an issue. In such cases, the boring is typically drilled with a 600 mm to 1200 mm diameter bucket, depending on the diameter of the required lifting equipment for personnel. Figure 3-4a shows a typical bucket auger. The bucket is typically 600 to 900 mm long and is basically an open-top metal cylinder having one or more slots cut in its base to permit the entrance of soil and rock as the bucket is rotated. At the slots the metal of the base is reinforced and teeth or sharpened cutting edge are provided to break up the material being sampled.

The boring is advanced by a rotating drilling bucket with cutting teeth mounted to the bottom. As shown in Figure 3-4b, the drilling bucket is attached to the bottom of a "kelly bar", which typically consists of two to four square steel tubes assembled one inside another so that they telescope downward, similar to a car radio antenna held upside down. At completion of each advancement, the bucket is retrieved from the boring and emptied on the ground near the drill rig.

Bucket auger borings are typically advanced by a truck-mounted drill. Small skid-mounted and A-frame drill rigs are available for special uses, such as drilling on steep hillsides or under low clearance (less than 2.5 m). Depending on the size of the rig and subsurface conditions, bucket augers are typically used to drill to depths of about 30 m or less, although large rigs with capabilities to drill to depths of 60 m or greater are available.

With the possible exception of running sand, the bucket auger is appropriate for most soil types and for soft to firm bedrock. Drilling below the water table can be completed where materials are firm and not prone to large-scale sloughing or water infiltration. For these cases the boring can be advanced by filling it with fluid (water or drilling mud), which provides a positive head and reduces the tendency for wall instability. Depending on hole conditions, down-hole logging is often precluded below water level. Down-hole inspection below zones of slow seepage can sometimes be performed, but must be preceded by careful inspection of hole conditions. Otherwise, down-hole logging below seepage zones should not be performed unless the hole is cased through the problem zone.

The bucket auger method is particularly useful for drilling in materials containing gravel and cobbles because the drilling bucket can often scoop up cobbles that may cause refusal for conventional drilling equipment. Also, because this type of rig drills in 300 to 600 mm increments and is emptied after each of these advances, it is advantageous where it is desirable to obtain large-volume samples from specific subsurface locations, such as for aggregate studies.

In hard materials (concretions or rocks larger than can enter the bucket), special-purpose buckets and attachments can be substituted for the standard "digging bucket". Examples of special attachments are:

- Coring buckets that are simply an open steel pipe with carbide cutting teeth mounted along the bottom edge of the pipe. These are used to core through hard materials.
- Rock buckets that have heavy-duty digging teeth and wider openings to collect broken materials.
- Single-shank breaking bars that are attached to the kelly bar and dropped to break up hard rock.
- Clam shells that are used to pick up cobbles and large rock fragments from the bottom of borings.

Only trained personnel should enter a bucket auger boring, and these borings should only be entered according to strict safety procedures established by the appropriate regulatory agencies. Care must be exercised to see that they are well ventilated and that there are not poisonous gases present when personnel enter for inspection or sampling. A good guideline for down-hole entry has been developed by ADSC (1995).

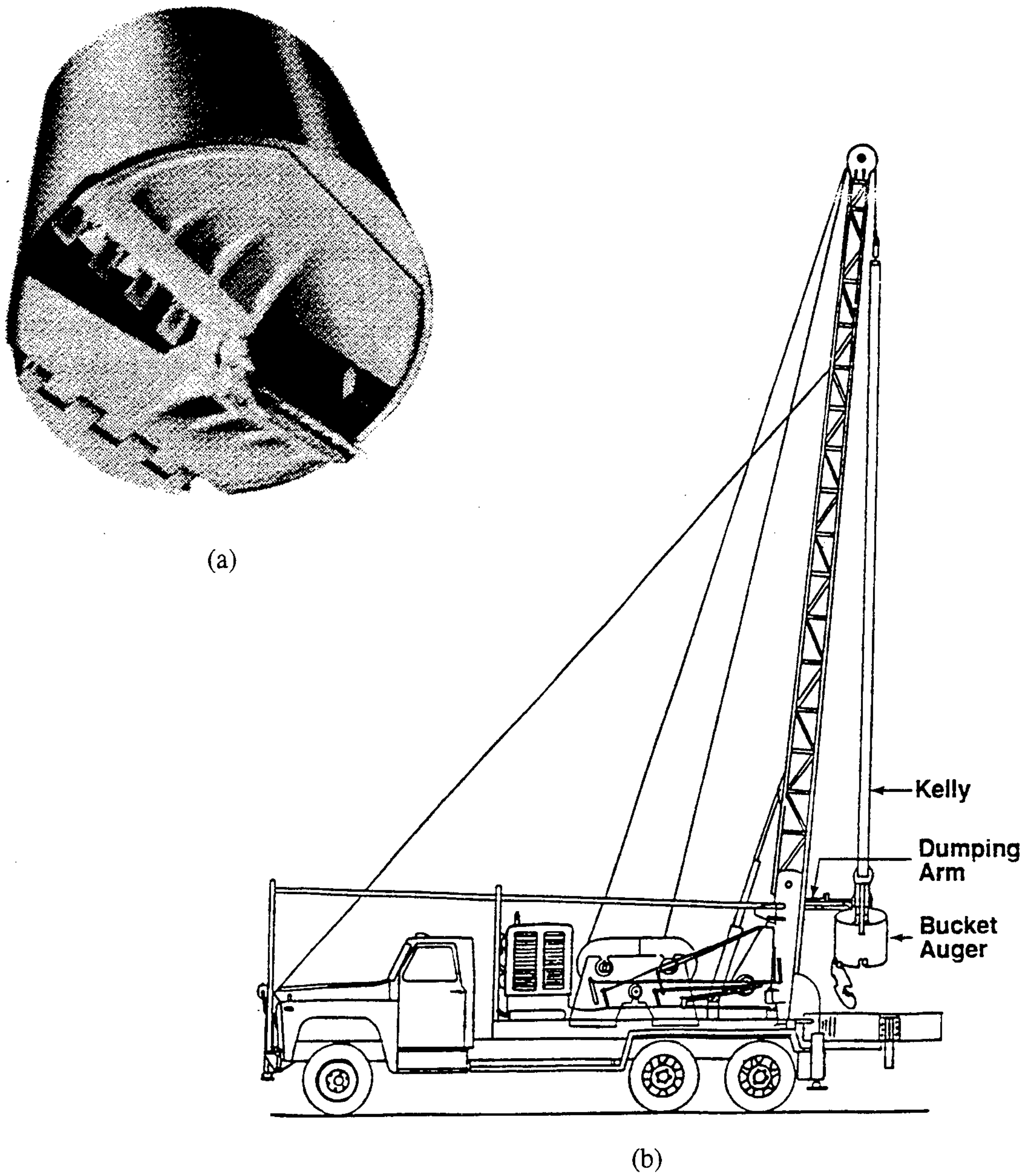


Figure 3-4: (a) Bucket Auger (Courtesy of Acker Drill Co., Inc.) (b) Typical Set-up of Bucket Auger and Drilling Rig. (ASTM 4700)

Rotary Wash Borings

The rotary wash boring method (Figures 3-5) is generally the most appropriate method for use in soil formations below the groundwater level. In rotary wash borings, the sides of the borehole are supported either with casing or with the use of a drilling fluid. Where drill casing is used, the boring is advanced sequentially by a) driving the casing to the desired sample depth, b) cleaning out the hole to the bottom of the casing, and c) inserting the sampling device and obtaining the sample from below the bottom of the casing.

The casing is usually selected based on the outside diameter of the sampling or coring tools to be advanced through the casing, but may also be influenced by other factors such as stiffness considerations for borings in water bodies or very soft soils, or dimensions of the casing couplings. Casing for rotary wash borings is typically furnished with inside diameters ranging from 60 mm to 130 mm. Even with the use of casing, care must be taken when drilling below the groundwater table to maintain at all times a head of water within the casing above the groundwater level. Particular attention must be given to adding water to the hole as the drill rods are removed after cleaning out the hole prior to sampling. Failure to maintain an adequate head of water may result in loosening or heaving (blow-up) of the soil to be sampled beneath the casing. Tables 3-2 and 3-3 present data on available drill rods and casings, respectively.

For holes drilled using drilling fluids to stabilize the borehole walls, casing should still be used at the top of the hole to protect against sloughing of the ground due to surface activity, and to facilitate circulation of the drilling fluid. In addition to stabilizing the borehole walls, the drilling fluid (water, bentonite, foam, Revert or other synthetic drilling products) also removes the drill cuttings from the boring. In granular soils and soft cohesive soils, bentonite or polymer additives are typically used to increase the weight of the drill fluid and thereby minimize stress reduction in the soil at the bottom of the boring. For borings advanced with the use of drilling fluids, it is important to maintain the level of the drilling fluid at or above the ground surface to maintain a positive pressure for the full depth of the boring. The driller must add drilling fluid as the drilling tools are removed.

For cleaning the borehole, drag bits are commonly used in cohesive soils and loose granular deposits, whereas roller bits are typically used to penetrate dense or coarse grained granular soils, cemented zones and soft or weathered rock.

Examination of the cuttings suspended in the wash fluid provides an opportunity to identify changes in the soil conditions between sample locations. A strainer is held in the drill fluid discharge stream to catch the suspended material. In some instances the drill water return is lost or significantly reduced. The loss of drill fluid is indicative of open joints, fissures, cavities, gravel layers or highly permeable zones, and must be carefully noted on the logs.

The properties of the drilling fluid and the quantity of water pumped through the bit will determine the size of particles that can be removed from the boring with the circulating fluid. In formations containing gravel, cobbles, or larger particles, coarse material may be left in the bottom of the boring. In these instances, clearing the bottom of the boring with a larger-diameter sampler (such as a 76 mm OD split-barrel sampler) may be needed to obtain a representative sample of the formation.

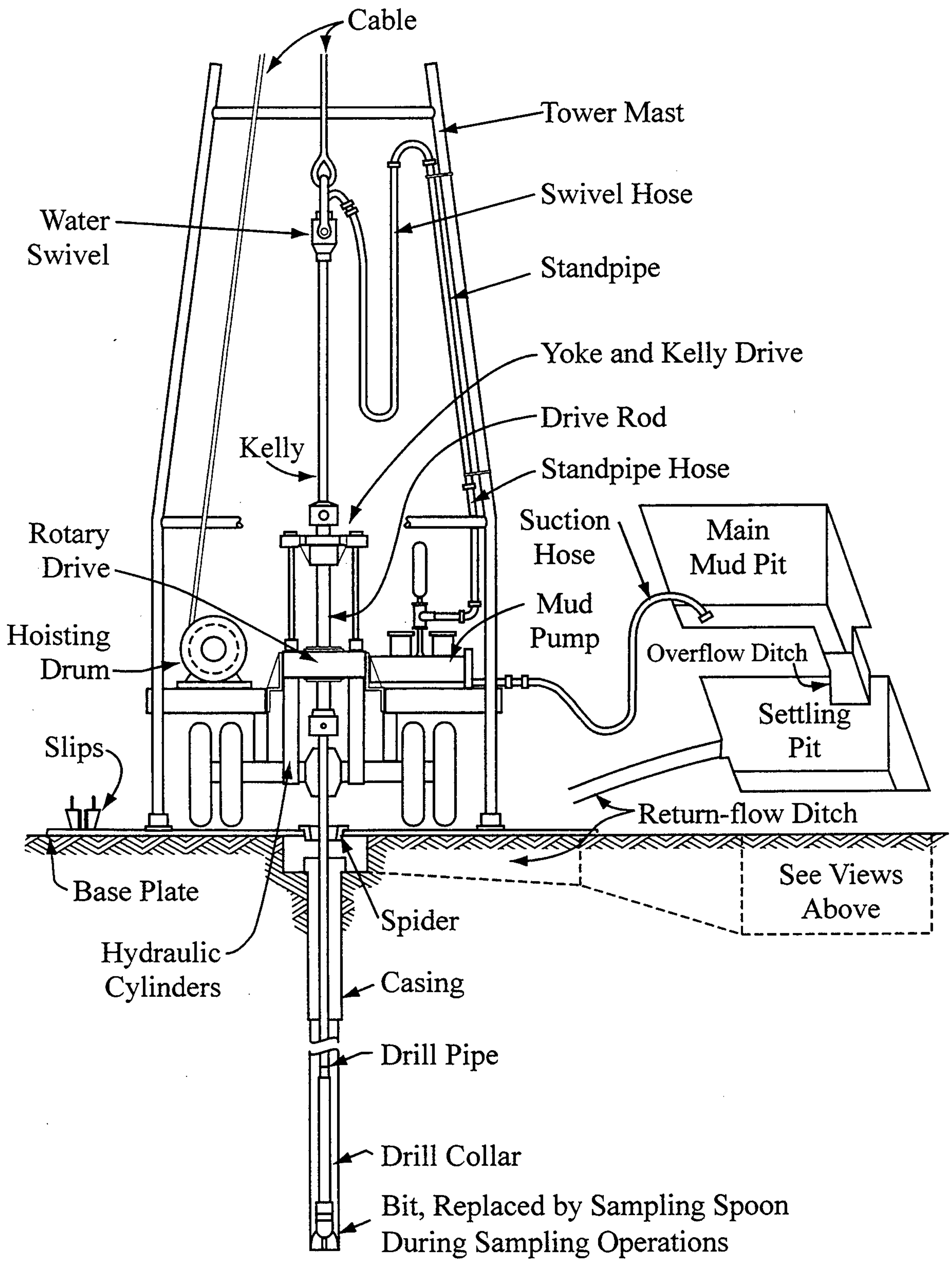
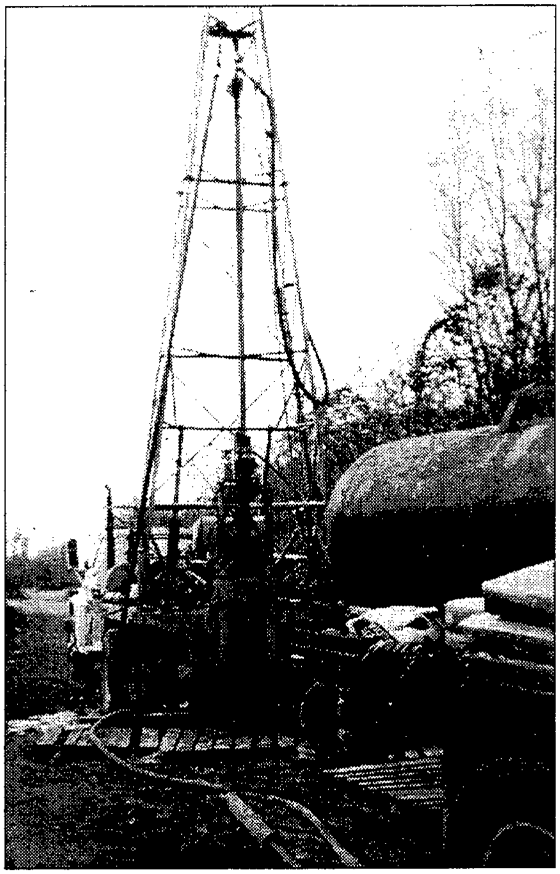


Figure 3-5: (a) Schematic of a Drilling Rig for Rotary Wash Methods. (After Hvorslev, 1948)



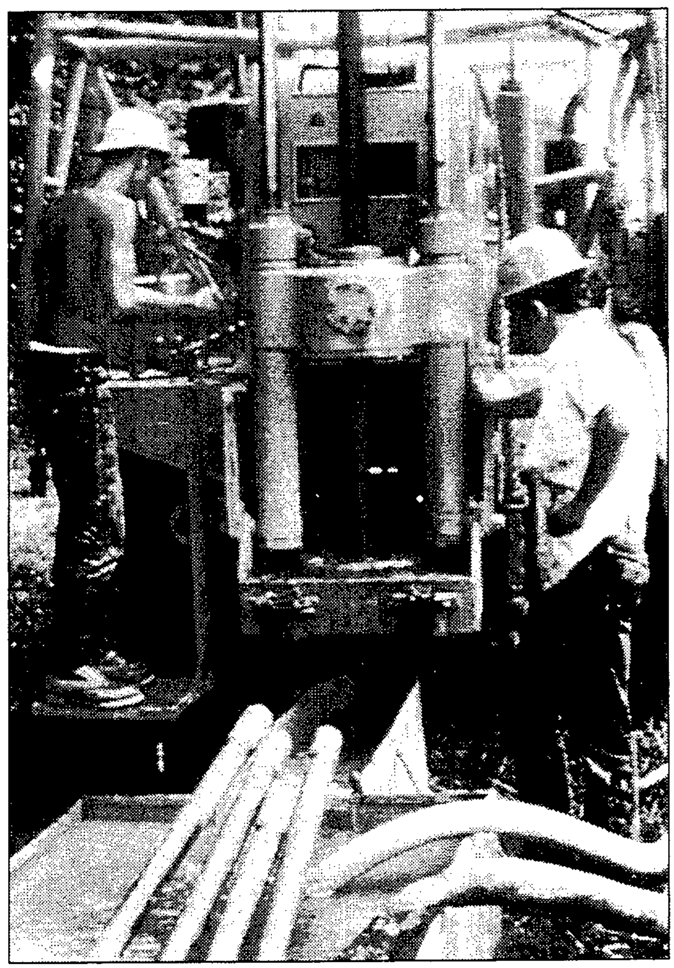


Figure 3-5 (b) Typical Equipment and Set-up of Rotary Wash Drilling. (Note Mud Pit in the Foreground in the lower Photograph).

TABLE 3-2
DIMENSIONS OF DRILL RODS
(Longyear Company and Christensen Dia-Min Tools, Inc.)

Size[a]	Outside Diameter of Rod (mm)	Inside Diameter of Rod (mm)	Inside Diameter of Coupling (mm)[b]
EX	33.3	21.4	11.1
AX	41.3	28.6	14.3
BX	48.4	35.7	15.9
NX	60.3	50.8	25.4
RW	27.8	18.3	10.3
EW	34.9	22.2	12.7
AW	44.4	31.0	15.9
BW	54.0	44.5	19.0
NW	66.7	57.2	34.9
HW	88.9	77.8	60.3
(L)AQWL	44.5	34.9	-
(C)AXWL	46.0	38.1	-
(L)BQWL	55.6	46.0	-
(C)BXWL	57.2	48.4	-
(L)NQWL	69.9	60.3	-
(C)NXWL	73.0	60.7	-
(L)HQWL	88.9	77.8	-
(C)HCWL	88.9	76.2	-
(L)PQWL	117.5[c]	103.2[c]	103.2
(C)CPWL	117.5	101.6	-

a X and W sizes are available from most manufacturers of drill rod. (L) indicates Longyear Company system. (C) indicates Christensen Dia-Min Tools, Inc. system.

b X and W series have a separate coupling. WL wireline series, except PQWL, are flush-joint, internally and externally, without a separate coupling.

c PQWL has a separate coupling, protruding outside the rod o.d., but internally flush. The outside diameter in table is o.d. of coupling. The outside diameter of rod is 114.3 mm.

TABLE 3-3
DIMENSIONS OF FLUSH-JOINT CASINGS
(Longyear Company and Christensen Dia-Min Tools, Inc.)

Size	Outside Diameter of Casing (mm)[a]	Inside Diameter of Casing (mm)[a]
RW	36.5	30.1
EW	46.0	38.1
AW	57.1	48.4
BW	73.0	60.3
NW	88.9	76.2
HW	114.3	101.6
PW	139.7	127.0
SW	168.3	152.4
UW	193.7	177.8
ZW	219.1	203.2

a No separate couplings. Connections are flush, internally and externally.

Area Specific Methods

Drilling contractors in different parts of the country occasionally develop their own subsurface exploration methods which may radically differ from the standard methods or may be a modification of standard methods.

These methods are typically developed to meet the requirements of local site conditions. For example, a hammer drill manufactured by Becker Drilling Ltd. of Canada (Becker Hammer) is used to penetrate gravel, dense sand and boulders such as in the "SGC" material present in Arizona.

Exploration Pit Excavation

Exploration pits and trenches permit detailed examination of the soil and rock conditions at a relatively low cost. Exploration pits can be an important part of geotechnical explorations where significant variations in soil conditions occur (vertically and horizontally), large soil and/or non-soil materials exist (boulders, cobbles, debris) that cannot be sampled with conventional methods, or buried features must be identified and/or measured.

Exploration pits are generally excavated with mechanical equipment (backhoe, bulldozer) rather than by hand excavation. The depth of the exploration pit is determined by the exploration requirements, but is typically about 2 to 3 m. In areas with high groundwater level, the depth of the pit may be limited by the water table. Exploration pit excavations are generally uneconomical at depths greater than about 5 m.

During excavation, the bottom of the pit should be kept relatively level so that each lift represents a uniform horizon of the deposit. At the surface, the excavated material should be placed in an orderly manner adjoining the pit with separate stacks to identify the depth of the material.

The U.S. Department of Labor's Construction Safety and Health Regulations, as well as regulations of any other governing agency must be reviewed and followed prior to excavation of the exploration pit, particularly in regard to shoring requirements.

The sides of the pit should be cleaned by chipping continuously in vertical bands, or by other appropriate methods, so as to expose a clean face of rock or soil.

Survey control at exploration pits should be done using optical survey methods to accurately determine the ground surface elevation and plan locations of the exploration pit. Measurements should be taken and recorded documenting the orientation, plan dimensions and depth of the pit, and the depths and the thickness of each stratum exposed in the pit.

See Section 3.3 for a description of procedures to backfill the exploration pit excavations.

<u>Logging Procedures</u>

The appropriate scale to be used in logging the exploration pit will depend on the complexity of geologic structures revealed in the pit and the size of the pit. The normal scale for detailed logging is 1:20 or 1:10, with no vertical exaggeration.

In logging the exploration pit a vertical profile should be made parallel with one pit wall. The contacts between geologic units should be identified and drawn on the profile, and the units sampled (if considered appropriate by the geotechnical engineer). Characteristics and types of soil or lithologic contacts should be noted. Variations within the geologic units must be described and indicated on the pit log wherever the variations occur. Sample locations should be shown in the exploration pit log and their locations written on a sample tag showing the station location and elevation. Groundwater should also be noted on the exploration pit log.

Photography

After the pit is logged, the shoring will be removed and the pit may be photographed at the discretion of the geotechnical engineer. Photographs should be located with reference to project stationing and baseline elevation. A visual scale should be included in each photograph.

3.1.2 Soil Samples

Soil samples obtained for engineering testing and analysis, in general, fit in one of the two following categories;

- Undisturbed
- Disturbed (but representative)

Undisturbed Samples

Undisturbed samples are typically obtained in cohesive soil strata for use in laboratory testing to determine the engineering properties of those soils. It should be noted that the term "undisturbed" soil sample refers to the relative degree of disturbance to the soil's in situ properties. Undisturbed samples are obtained with specialized equipment designed to minimize the disturbance to the in situ structure and moisture content of the soils. Specimens obtained by undisturbed sampling methods are used to determine the strength, stratification, permeability, density, consolidation, dynamic properties and other engineering characteristics of soils.

Disturbed Samples

Disturbed samples are those obtained using equipment that destroy the macro structure of the soil but do not alter its mineralogical composition. Specimens from these samples can be used for determining the general lithology of soil deposits, for identification of soil components and general classification purposes, for determining grain size, Atterberg limits and compaction characteristics of soils, as well as correlations to other engineering characteristics (i.e. permeability, strength). Disturbed samples can be obtained with mechanical or hand augers, split barrel samplers, small excavation machines, or small hand tools.

3.1.3 Soil Samplers

A wide variety of samplers are available to obtain soil samples for geotechnical engineering projects. These include standard sampling tools which are widely used as well as specialized types which may be unique to certain regions of the country to accommodate local conditions and preferences. The following discussions are general guidelines to assist geotechnical engineers and field supervisors select appropriate samplers, but in many instances local practice will control. Following is a discussion of the more commonly used types of samplers.

Split Barrel Sampler

The split-barrel (or split spoon) sampler is used to obtain samples in all types of soils. The split spoon sampler is typically used in conjunction with the Standard Penetration Test (SPT), as specified in AASHTO T 206 and ASTM D 1586, in which the sampler is driven with a 63.5 kg hammer dropping from a height of 760 mm. Details of the Standard Penetration Test are discussed in Section 5.1.

In general, the split-barrel samplers are available in standard lengths of 457 mm and 610 mm with inside diameters ranging from 38.1 to 114.3 mm in 12.7 mm increments. The 38.1 mm inside diameter sampler (see Figure 3-6a) is popular because correlations have been developed between the number of blows required for penetration and several soil properties (see Chapter 9). The larger-diameter samplers are used when gravel particles are present or when more material is needed for classification tests.

The 38.1 mm inside diameter standard split barrel sampler has an outside diameter of 51 mm and a cutting shoe with an inside diameter of 34.9 mm. This corresponds to a relatively thick-walled sampler with an area ratio defined by Hvorslev (1949) of 112 percent. This high area ratio disturbs the natural characteristics of the soil being sampled, thus samples obtained as such are not considered undisturbed.

A ball check valve incorporated in the sampler head facilitates the recovery of cohesionless materials. This valve seats when the sampler is being withdrawn from the borehole, thereby preventing water pressure on the top of the sample from pushing it out. If the sample tends to slide out because of its weight, vacuum tends to develop at the top of the sample to retain it.

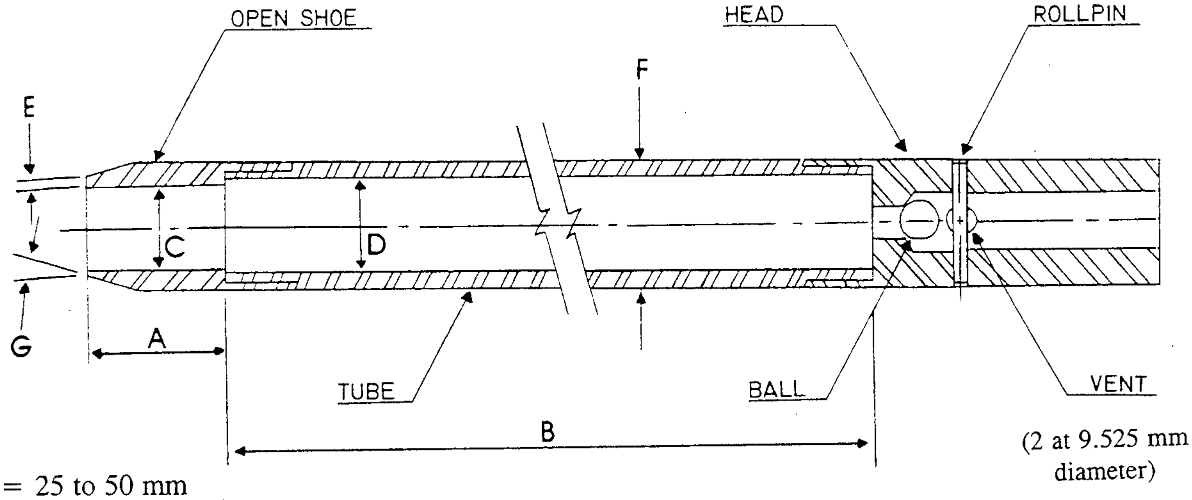
As shown in Figure 3-6b, when the shoe and the sleeve of this type of sampler are unscrewed from the split barrel, the two halves of the barrel may be separated and the sample may be extracted easily. The soil sample is removed from the split-barrel sampler and placed and sealed in a glass jar, sealed in a plastic bag, or a brass liner. Separate containers should be used if the sample contains different soil types. Since samples obtained with split barrels are disturbed they are not suitable for use in tests requiring the use of undisturbed specimens.

Steel or plastic sample retainers are often required to keep samples of clean granular soils in the split-barrel sampler. Figure 3-7 shows a basket shoe retainer, a spring retainer and a trap valve retainer. They are inserted inside the sampler between the shoe and the sample barrel to help retain loose or flowing materials. These retainers permit the soil to enter the sampler during driving but upon withdrawal they close and thereby retain the sample. Use of sample retainers should be noted on the boring log.

The following information should be written on a label attached to the sample container: project number, date, boring number, sample number, depth interval, and driving resistance in blows per each 150 mm interval. In addition to this information, the boring log should also note the length of sample recovered and provide a detailed description of the soils recovered in the sampler.

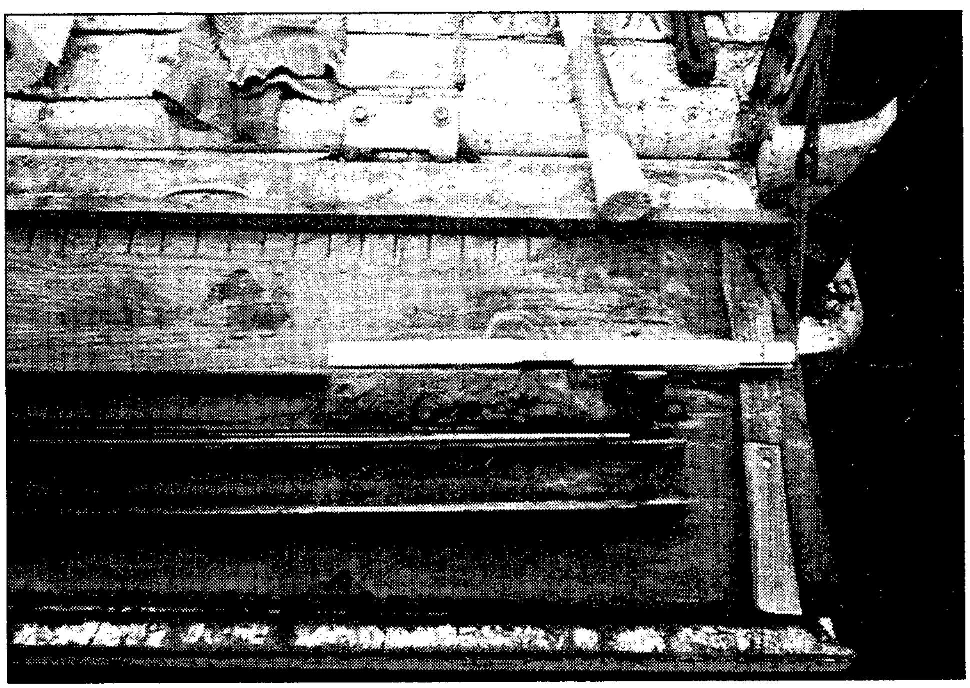
Thin Wall Sampler

The thin-wall tube (Shelby) sampler is commonly used to obtain relatively undisturbed samples of cohesive soils for strength and consolidation testing. The sampler commonly used (Figures 3-8) has a 76 mm outside diameter, a 73 mm inside diameter and a corresponding area ratio of 9 percent. Larger diameter sampler tubes are often used where higher quality samples are required and sampling disturbance must be reduced. The test method for thin-walled tube sampling is described in AASHTO T 207 and ASTM D 1587.



A = 25 to 50 mm
B = 0.457 to 0.762 m
C = 34.93 ± 0.13 mm
D = 38.1 ± 1.3 - 0.0 mm
E = 2.54 ± 0.25 mm
F = 50.8 ± 1.3 - 0.0 mm
G = 16.0° to 23.0°

(a)



(b)

Figure 3-6: (a) Split Barrel Sampler (ASTM D 1586), (b) Split Barrel Sampler Opened Longitudinally with a Soil Sample.

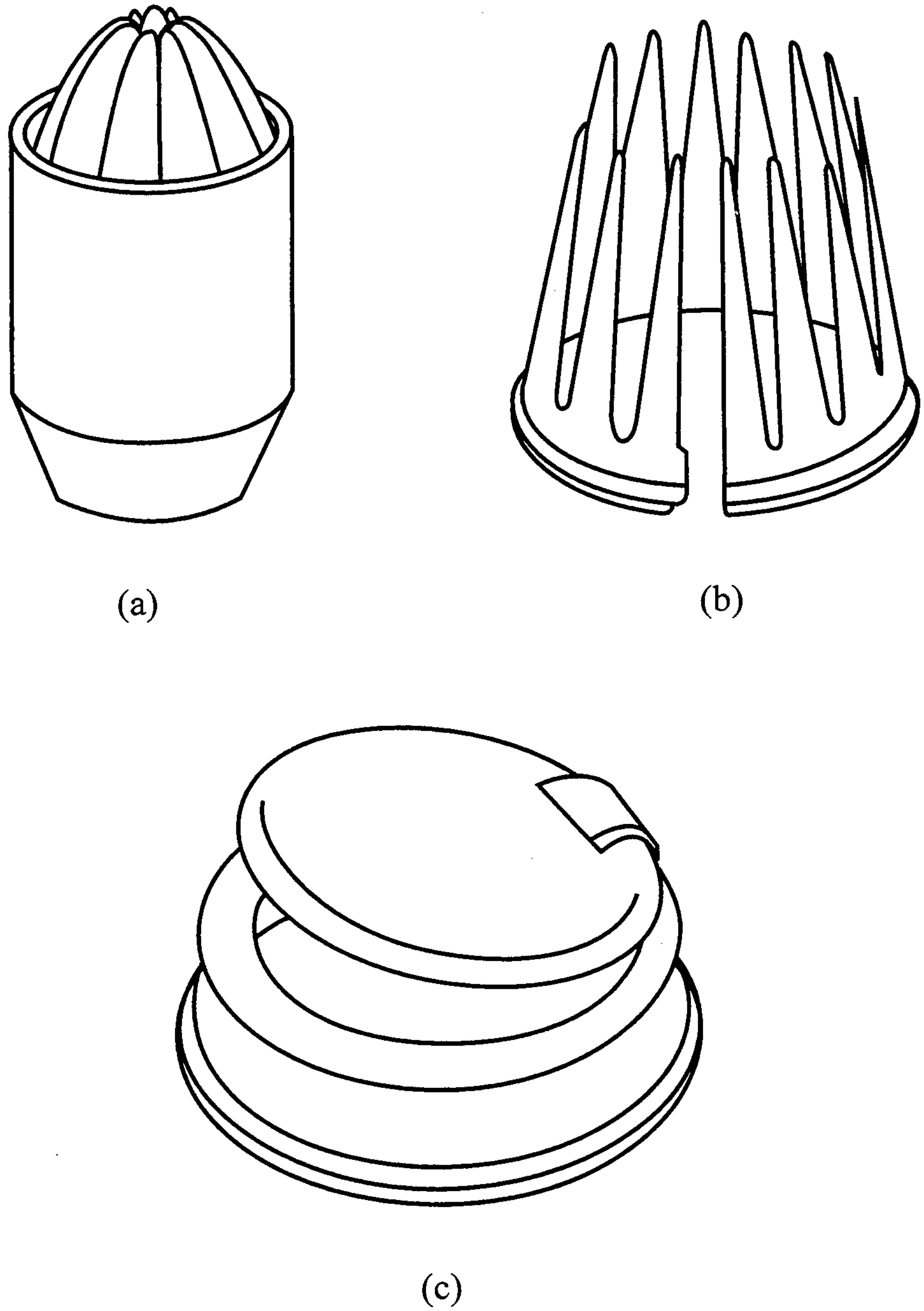
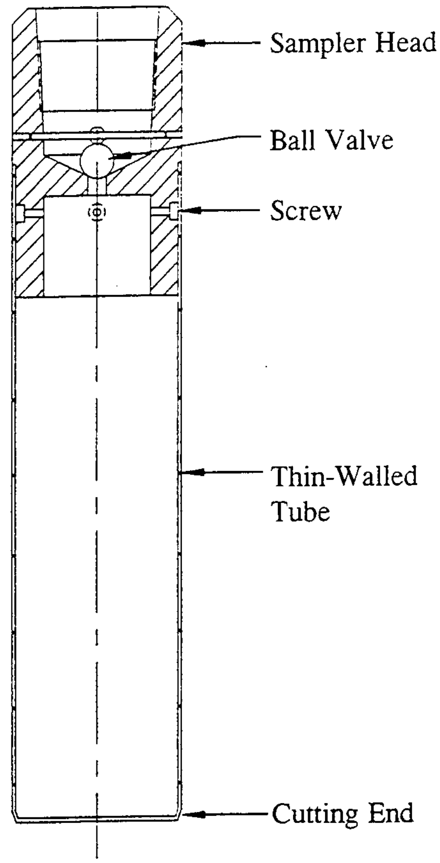
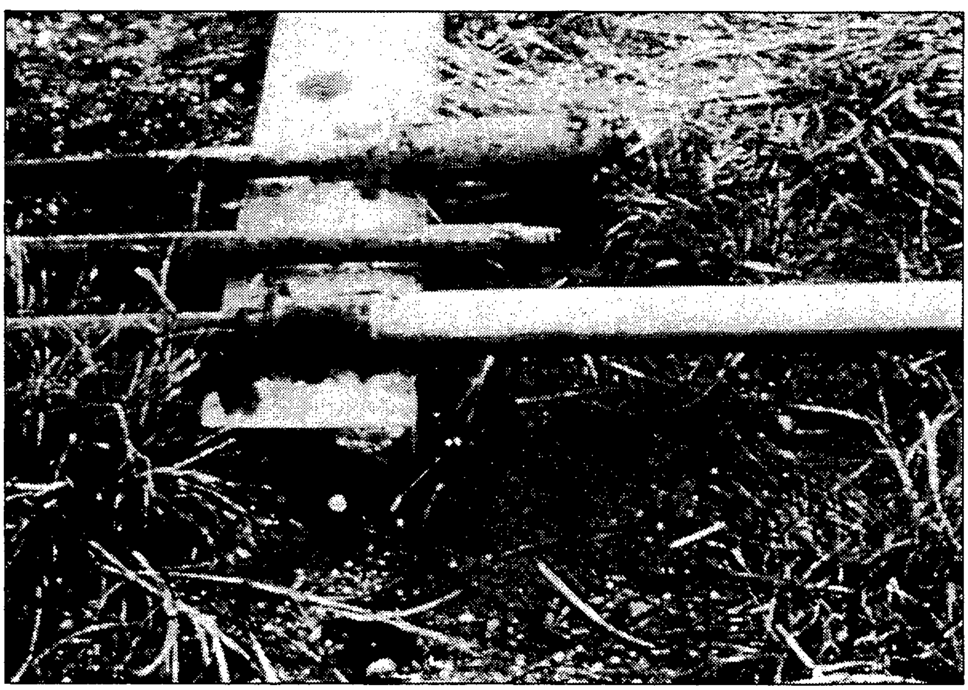


Figure 3-7: Sample Retainers (a) Basket Shoe - the flexible fingers open to admit the sand then close when the tube is withdrawn, (b) Spring Sample Retainer, (c) Trap Valve Sample Retainers used to Recover Muds and Watery Samples. (After Acker, 1974)



(a)



(b)

Figure 3-8: (a) Schematic of Thin-Walled (Shelby) Tube (After ASTM D 4700), (b) Photograph of a Thin-Walled (Shelby) Tube

The thin-walled tubes are manufactured using carbon steel, galvanized-coated carbon steel, stainless steel, and brass. The carbon steel tubes are often the lowest cost tubes but may be unsuitable if the samples are to be stored in the tubes for more than a few days or if the inside of the tubes becomes rusty, significantly increasing the friction between the tube and the soil sample. In stiff soils, galvanized carbon steel tubes are preferred since carbon steel is stronger, less expensive and galvanizing provides a degree of protection from corrosion. In offshore conditions (i.e., bridge borings), or where the samples may be stored for long time periods, stainless steel tubes are preferred. The thin-walled tube is manufactured with a special cutting edge for cutting a reduced-diameter sample (commonly 72 mm inside diameter) that helps reduce friction between the soil sample and tube. It is important that this special cutting edge be maintained in good condition. The thin-wall tubes can be pushed with a fixed head or piston head. The piston sampler is described later.

The thin-wall tube sampler should not be pushed more than the total length up to the connecting cap less 75 mm; the remaining 75 mm (minimum) of tube length is provided to accommodate the slough that accumulates to a greater or lesser extent at the bottom of the boring. Typically, sample length is approximately 600 mm. Where low density soils or soils sensitive to collapse are being sampled, a reduced push of 300 to 450 mm may be appropriate to prevent the disturbance of the sample. The thin-walled tube sampler should be slowly pushed with a single, continuous motion using the drill rig's hydraulic system. The hydraulic pressure required to advance the thin-walled tube sampler should be noted and recorded on the log. The sampler head contains a check valve that allows water to pass through the sampling head into the drill rods. This check valve must be clear of mud and sand and should be checked prior to each sampling attempt. After the push is completed, the driller should wait at least ten minutes to allow the sample to swell slightly within the tube, then rotate the drill rod string through two complete revolutions to shear off the sample, and then slowly and carefully bring the sample to the surface. In stiff soils it is often unnecessary to rotate the sampler.

After taking a thin-walled tube sample, slough or cuttings from the upper end of the tube should be removed using a cleanout tool. The length of sample recovered should be measured and the soil classified for the log. The material at the bottom end of the tube should be removed to a maximum depth of 25 mm, and the cuttings placed in a properly labeled storage jar. Both ends of the tube should then be sealed with at least a 25 mm thick layer of microcrystalline (nonshrinking) wax after placing a plastic disk to protect the ends of the sample. The remaining void above the top of the sample should be filled with moist sand. Plastic end caps should then be placed over both ends of the tube and electrician's tape should be placed over the joint between the collar of the cap and the tube and over the screw holes. The capped ends of the tubes are then dipped in molten wax. The samples must be stored upright in a protected environment to keep them from freezing and from contact with direct sunlight or high temperatures which may reduce moisture content.

In some areas of the country, the thin-walled tube samples are field extruded, rather than transported to the laboratory in the tube. This practice is generally not desirable due to the uncontrolled conditions typical of field operations, and must not be used if the driller does not have established procedures and equipment for preservation and transportation of the extruded samples.

The following information should be written on the top half of the tube and on the top end cap: project number, boring number, sample number, and depth interval. The field supervisor should also write on the tube the project name and the date the sample was taken. Near the upper end of the tube, the word "top" and an arrow pointing toward the top of the sample should be included. Putting sample information on both the tube and the end cap facilitates retrieval of tubes from laboratory storage and helps prevent mix-ups in the laboratory when several tubes may have their end caps removed at the same time.

Piston Sampler

The piston sampler (Figure 3-9) is basically a thin-wall tube sampler with a piston, piston rod, and a modified sampler head. This sampler, also known as Osterberg or Hvorslev sampler, is particularly useful for sampling soft soils although it can also be used in stiff cohesive soils.

The sampler, with its piston located at the base of the sampling tube, is lowered into the borehole. When the sampler reaches the bottom of the hole, the piston rod is held fixed relative to the ground surface and the thin-wall tube is pushed into the soil slowly by hydraulic pressure or mechanical jacking. The sampler is never driven. Upon completion of sampling, the sampler is removed from the borehole and the vacuum between the piston and the top of the sample is broken by means of a vacuum-breaking device provided for this purpose in the piston. The piston head and the piston are then removed from the tube and jar samples are taken from the top and bottom of the sample for identification purposes. The tube is then labeled and sealed in the same way as a Shelby tube described in the previous section.

The quality of the samples obtained is excellent and the probability of obtaining a satisfactory sample is high. One of its major advantages is that the fixed piston tends to prevent the entrance of excess soil at the beginning of sampling, thus precluding recovery ratios greater than 100 percent. It also tends to prevent too little soil from entering near the end of sampling. Thus, the opportunity for 100 percent recovery is enhanced. The head used on this sampler also acts more positively to retain the sample than the ball valve of the thin-wall tube (Shelby) samplers.

Pitcher Tube Sampler

The pitcher tube sampler is used in stiff to hard clays and soft rocks, and is well adapted to sampling deposits consisting of alternately hard and soft layers. The primary components of this sampler as shown in Figure 3-10 are an outer rotating core barrel with a bit and an inner stationary, spring-loaded, thin-wall sampling tube that leads or trails the outer barrel drilling bit, depending on the hardness of the material being penetrated.

When the drill hole has been cleaned, the sampler is lowered to the bottom of the hole (Figure 3-9a). When the sampler reaches the bottom of the hole, the inner tube meets resistance first and the outer barrel slides past the tube until the spring at the top of the tube contacts the top of the outer barrel. At the same time, the sliding valve closes so that the drilling fluid is forced to flow downward in the annular space between the tube and the outer core barrel and then upward between the sampler and the wall of the hole. If the soil to be penetrated is soft, the spring will compress slightly (Figure 3-9b) and the cutting edge of the tube will be forced into the soil as downward pressure is applied. This causes the cutting edge to lead the bit of the outer core barrel. If the material is hard, the spring compresses a greater amount and the outer barrel passes the tube so that the bit leads the cutting edge of the tube (Figure 3-9c). The amount by which the tube or barrel leads is controlled by the hardness of the material being penetrated. The tube may lead the barrel by as much as 150 mm and the barrel may lead the tube by as much as 12 mm. Sampling is accomplished by rotating the outer barrel at 100 to 200 revolutions per minute (rpm) while exerting downward pressure. In soft materials sampling is essentially the same as with a thin-wall sampler and the bit serves merely to remove the material from around the tube. In hard materials the outer barrel cuts a core, which is shaved to the inside diameter of the sample tube by the cutting edge and enters the tube as the sampler penetrates. In either case, the tube protects the sample from the erosive action of the drilling fluid at the base of the sampler. The filled sampling tube is then removed from the sampler and is marked, preserved, and transported in the same manner described above for thin-walled tubes.

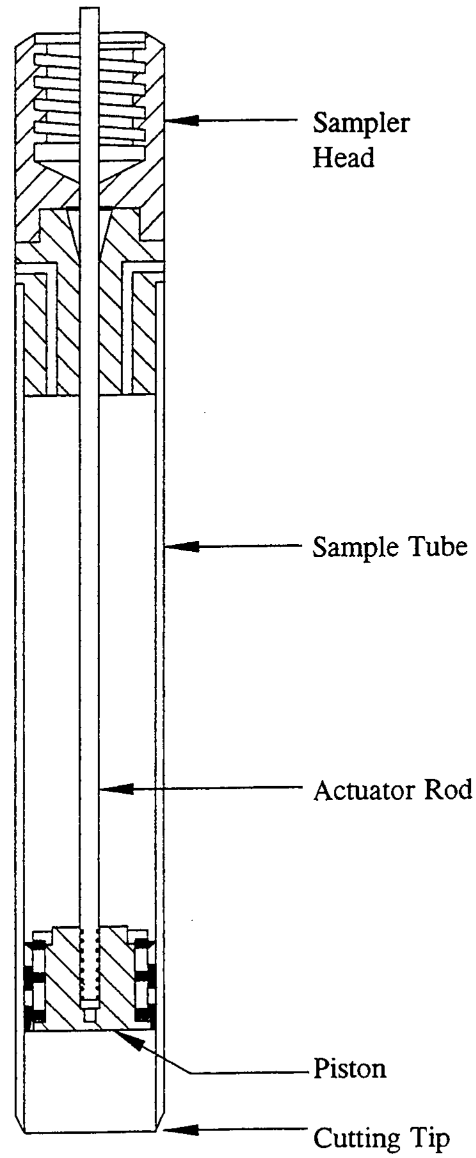


Figure 3-9: Piston Sampler. (After ASTM D 4700)

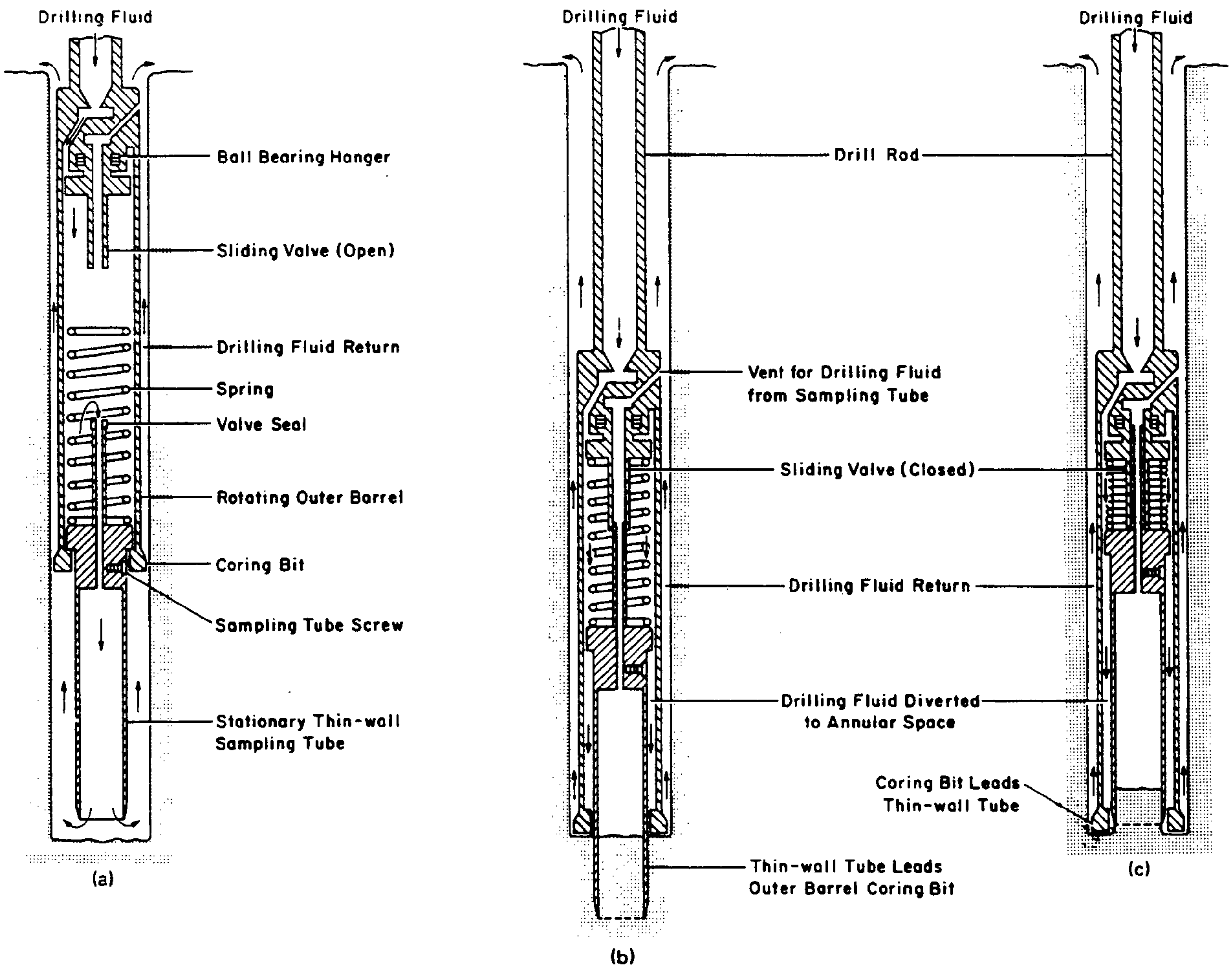


Figure 3-10: Pitcher Sampler. Schematic Drawing Showing: (a) Sampler Being Lowered into Drill Hole; (b) Sampler During Sampling of Soft Soils, (c) Sampler During Sampling of Stiff or Dense Soils. (Courtesy of Mobile Drilling, Inc.)

Denison Sampler

A Denison sampler is similar to a pitcher sampler except that the projection of the sampler tube ahead of the outer rotating barrel is manually adjusted before commencement of sampling operations, rather than spring-controlled during sampler penetration. The basic components of the sampler (Figure 3-11) are an outer rotating core barrel with a bit, an inner stationary sample barrel with a cutting shoe, inner and outer barrel heads, an inner barrel liner, and an optional basket-type core retainer. The coring bit may either be a carbide insert bit or a hardened steel sawtooth bit (see Figure 3-17). The shoe of the inner barrel has a sharp cutting edge. The cutting edge may be made to lead the bit by 12 mm to 75 mm through the use of coring bits of different lengths. The longest lead is used in soft and loose soils because the shoe can easily penetrate these materials and the longer penetration is required to provided the soil core with maximum protection against erosion by the drilling fluid used in the coring. The minimum lead is used in hard or dense soils and in soils containing gravel.

The Denison sampler is used primarily in stiff to hard cohesive soils and in sands, which are not easily sampled with thin-wall samplers owing to the large jacking force required for penetration. Samples of clean sands may be recovered by using driller's mud, a vacuum valve, and a basket catch. The sampler is also suitable for sampling soft cohesive soils.

Modified California Sampler

The Modified California sampler (Figure 3-12) is a lined sampler in common use in the Midwest and West, but rarely used in the East and South. The sampler is thick-walled (area ratio of 77 percent) with a sampler barrel that has an outside diameter of 64 mm and an inside diameter of 51 mm. This sampler generally has a cutting shoe similar to the split-barrel sampler, but with an inside diameter of generally 49 mm. Four 102 mm long 49 mm ID brass liners are used to contain the sample. In the West, the Modified California sampler is driven with standard penetration energy. The unadjusted blow count is recorded on the boring log. In the Midwest the sampler is generally pushed hydraulically. When pushed, the hydraulic pressure required to advance the Modified California sampler should be noted and recorded on the log. The driving resistance obtained using a Modified California sampler must be adjusted to correspond to the standard penetration test driving resistance.

Continuous Soil Sampler

Several types of thick-walled, 1.5 m long samplers are presently available to obtain "continuous" samples of soil as hollow-stem augers are advanced into cohesive soil formations. These systems use bearings or fixed hexagonal rods to restrain or reduce rotation of the continuous sampler as the hollow-stem augers are advanced and the tube is pushed into undisturbed soil below the augers. The continuous samples are commonly used for visual observation, hand penetrometer tests, and classification-type laboratory tests (moisture, density). Experience shows the sampler works acceptably in most cohesive soils and in soils with thin sand layers. The continuous sampler is not considered suitable for formations of cohesionless soil below the groundwater level, soft soils, or samples that swell following sampling. Information is limited regarding the suitability of the continuous samples for strength and consolidation tests.

Other Soil Samplers

A variety of special samplers are available to obtain samples of soil and soft rocks. These methods include the retractable plug, Sherbrooke, and Laval samplers. These sampling methods are used in difficult soils where the more routine methods do not recover samples.

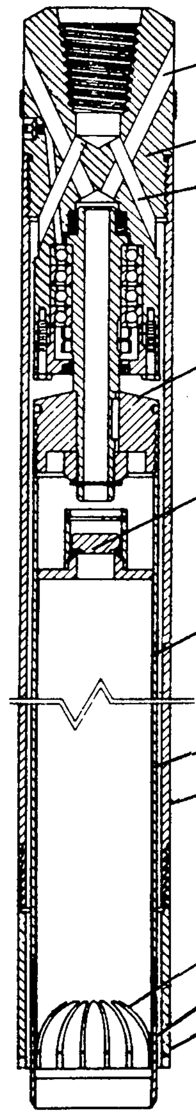


Figure 3-11: Dension Double-Tube Core Barrel Soil Sampler (Courtesy of Sprague & Henwood, Inc.)

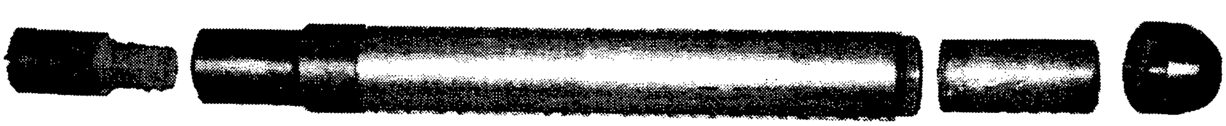


Figure 3-12: Modified California Sampler

Bulk Samples

There are a number of tests that can use or require the use of disturbed bulk samples. Bulk samples are suitable for R-value, compaction, California Bearing Ratio (CBR), and other laboratory test methods to be discussed later. Bulk samples may also be required for grain size analyses to obtain representative gradation of coarse grained material (cobbles, gravel, etc.).

Bulk soil samples may be obtained by collecting soil using hand tools without any precautions to minimize sample disturbance. The sample may be taken from the base or walls of a test pit or a trench, from drill cuttings, from a hole dug with a shovel and other hand tools, or from a stockpile. The sample should be put into a container that will retain all of the particle sizes. For large samples, plastic or metal buckets or metal barrels are used; for smaller samples, heavy plastic bags that can be sealed to maintain the water content of the samples are used.

For projects where the determination of the undisturbed properties is very critical, and where the soil layers of interest are accessible, undisturbed bulk samples can be of great value. Of all undisturbed testing methods discussed in this manual, properly obtained bulk samples produce samples with the least amount of disturbance. Such samples can be obtained from the hillsides, cuts, test pits, tunnel walls and other exposed sidewalls. Undisturbed bulk sampling is limited to cohesive soils and rocks. The procedures used for obtaining undisturbed samples vary from cutting large blocks of soil using a combination of shovels, hand tools and wire saws to using small knives and spatulas to obtain small blocks.

If the material is relatively homogeneous, then bulk samples may be taken equally well by hand or by machine. However, in stratified materials, hand excavation may be required. In the sampling of such materials it is necessary to consider the manner in which the material will be excavated for construction. If it is likely that the material will be removed layer by layer through the use of scrapers, samples of each individual material will be required and hand excavation from base or wall of the pit may be a necessity to prevent unwanted mixing of the soils. If, on the other hand, the material is to be excavated from a vertical face, then the sampling must be done in a manner that will produce a mixture having the same relative amounts of each layer as will be obtained during the borrow area excavation. This can usually be accomplished by hand-excavating a shallow trench down the walls of the test pit within the depth range of the materials to be mixed.

Once samples are obtained and transported to the laboratory in suitable containers, they are trimmed to appropriate size and shape for testing. Block samples should be wrapped with household plastic membrane and heavy duty foil and stored in block form and only trimmed shortly before testing. Each bulk sample must be identified with the following information: project number, boring or exploration pit number, sample number, sample depth and orientation.

3.1.4 Sampling Interval and Appropriate Type of Sampler

In general, SPT samples are taken in both granular and cohesive soils, and thin-walled tube samples are taken in cohesive soils.

The sampling interval will vary between individual projects and between regions. A common practice is to obtain split barrel samples at 0.75 m intervals in the upper 3 m and at 1.5 m intervals below 3 m. In some instances, a greater sample interval, often 3 m, is allowed below depths of 30 m. In other cases, continuous samples may be required for some portion of the boring.

In cohesive soils, at least one undisturbed soil sample should be obtained from each different stratum encountered. If a uniform cohesive soil deposit extends for a considerable depth, additional undisturbed samples are commonly obtained at 3 to 6 m intervals. Where borings are widely spaced, it may be appropriate to obtain undisturbed samples in each boring; however, for closely spaced borings, or in deposits which are generally uniform in lateral extent, undisturbed samples are commonly obtained only in selected borings. In erratic geologic formations or thin clay layers it is sometimes necessary to drill a separate boring adjacent to a previously completed boring to obtain an undisturbed sample from a specific depth which may have been missed in the first boring.

3.1.5 Sample Recovery

Occasionally, sampling is attempted, but there may be little or no material recovered. In cases where a split barrel, or an other disturbed-type sample is to be obtained, it is appropriate to make a second attempt to recover the soil sample immediately following the first failed attempt. In such instances, the sampling device is often modified to include a retainer basket, a hinged trap valve, or other measures to help retain the material within the sampler.

In cases where an undisturbed sample is desired, the field supervisor should direct the driller to drill to the bottom of the attempted sampling interval and repeat the sampling attempt. The method of sampling should be reviewed, and the sampling equipment should be checked to understand why no sample was recovered (such as a plugged ball valve). It may be appropriate to change the sampling method and/or the sampling equipment, such as waiting a longer period of time before extracting the sampler, extracting the sampler more slowly and with greater care, etc. This process should be repeated or a second boring may be advanced to obtain a sample at the same depth.

3.1.6 Sample Identification

Every sample which is attempted, whether recovered or not, should be assigned a unique number composed of designators for the project number or name, boring number, sequential sample attempt number, and sample depth. Each sample should be given a unique number. Where tube samples are obtained, any disturbed tubes should be clearly marked as such.

3.1.7 Relative Strength Tests

In addition to the visual observations of soil strength, a pocket (hand) penetrometer can be used to estimate the strength of soil samples. The hand penetrometer estimates the unconfined strength and is suitable for firm to very stiff clay soils. A larger foot/adaptor is needed to test softer soils. It should be emphasized that this test does not produce absolute values; rather it should be used as a guide in estimating the relative strength of soils.

Another useful field test device is a torvane (shown in Figure 3-13), which is a small diameter vane shear testing device that provides an estimate of the shear strength of cohesive soils. Variable diameter vanes are available for use in very soft to very stiff cohesive soils.

Testing with a penetrometer or torvane should always be done in natural soils as near as possible to the center of the top or bottom end of the sample. Testing on the sides of extruded samples is not acceptable. Strength values obtained from pocket penetrometer or torvane should not be used for design purposes.

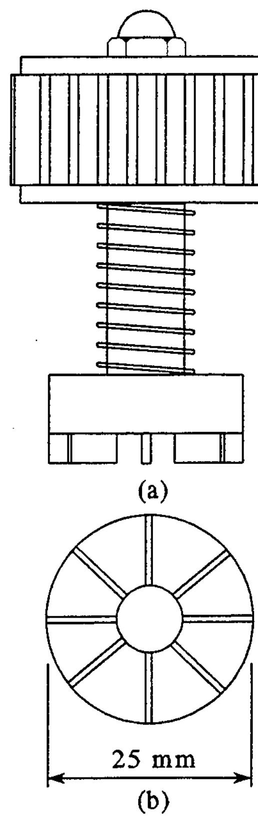


Figure 3-13: Torvane Device

3.1.8 Care and Preservation of Undisturbed Soil Samples

Each step in sampling, extruding, storing and testing introduces varying degrees of disturbance to the sample. Proper sampling, handling, and storage methods are essential to minimize these disturbances. The geotechnical engineer must be cognizant of disturbance introduced during the various steps in sampling through testing. The field supervisors should be sensitized about these disturbances and their consequences, and they should be trained to avoid or minimize them. A detailed discussion of sample preservation and transportation is presented in ASTM D 4220.

When tube samples are to be obtained, each of the supplied sampling tubes must be examined to assure that they are not bent, that the cutting edges are not damaged, and that the interior of the tubes are not corroded. If the walls of the tube are corroded or irregular, or if samples are stored in tubes for long periods of time, the force required to extract the samples sometimes may exceed the shear strength of the sample causing increased sample disturbance.

All samples should be protected from extreme temperatures. Samples should be kept out of direct sunlight and should be covered with wet burlap or other material in hot weather. In winter months, special precautions should be taken to prevent samples from freezing during handling, shipping and storage. As much as is practical, the thin-walled tubes should be kept vertical, with the top of the sample oriented in the up position. If available, the thin-walled tubes should be kept in a carrier with an individual slot for each tube. Padding should be placed below and between the tubes to cushion the tubes and to prevent them from striking one another. The entire carrier should be secured with rope or cable to the body of the transporting vehicle so that the entire case will not tilt or tip over while the vehicle is in motion. Figure 3-14 shows a container for shipping tube samples.

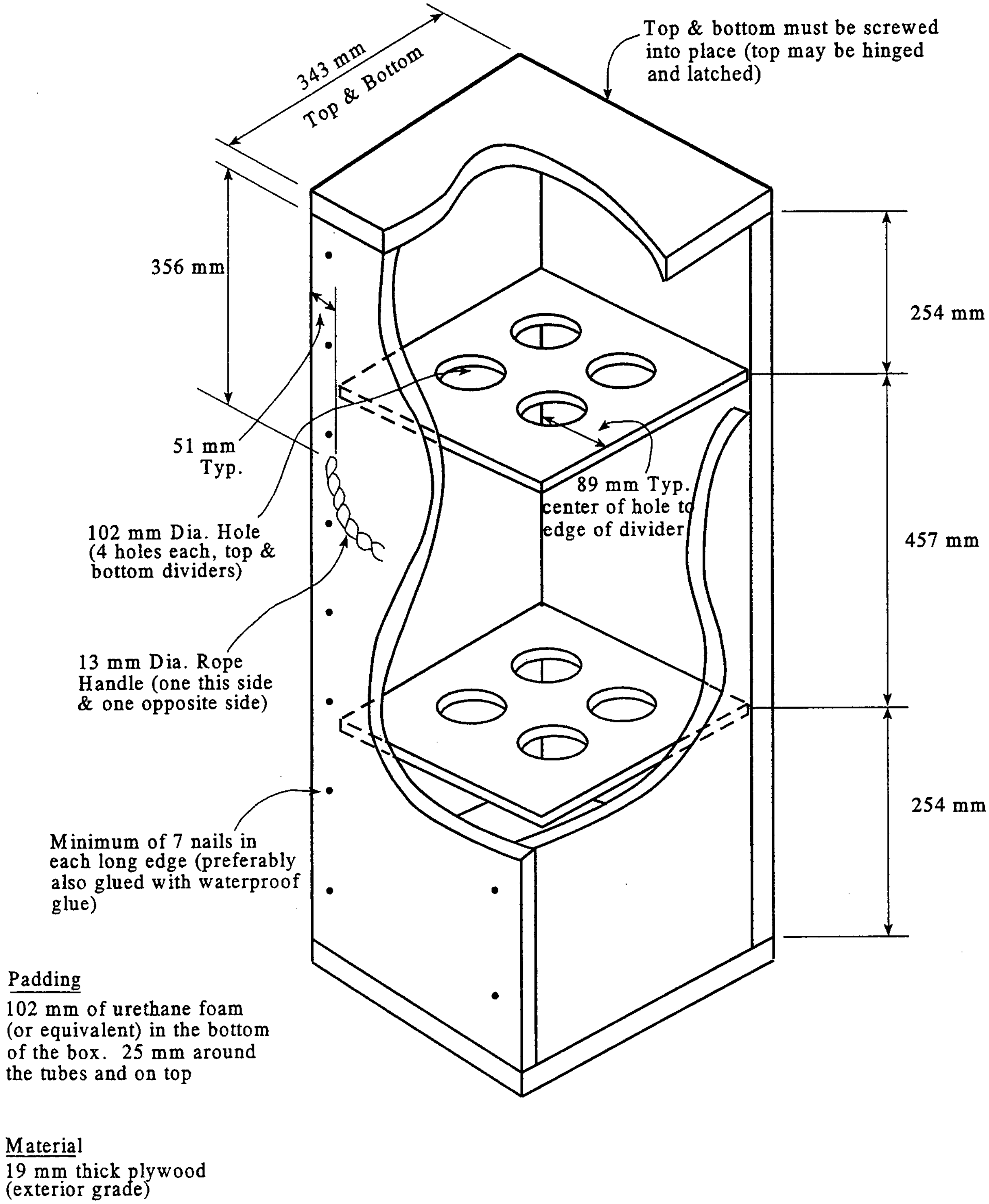


Figure 3-14: Shipping Container for 76 mm Thin-Walled Tubes (ASTM D 4220)

Samples extracted in the field or laboratory are often wrapped in clear plastic sheeting and/or in aluminum foil (Figure 3-15). Depending on the pH of the soil, the aluminum foil may react with the surface of the soil with which it comes in contact. This will result in developing a thin layer of discolored soil over the entire surface of the sample, thus making visual identification difficult and confusing. It may also result in changes in the moisture distribution across the sample. Even though plastic sheeting is also susceptible to reacting with the soil they come in contact with, past observation shows that plastic sheeting has less effect than foil. Thus it is recommended that extruded soil samples which are to be preserved be wrapped in plastic sheeting and then wrapped with foil. In general, samples should not be extracted in the field.

Some agencies still use the practice of storing extracted samples in ice cream boxes which are filled with paraffin. This practice has high probability of causing significant disturbances in sample properties. For example, after samples are placed in the containers the annular space, the top and the bottom of the containers are filled with hot paraffin. Sudden heating of the surface of the sample causes "sweating", and changes the internal moisture regime of the sample. The removal of the sample, in the laboratory, from the hardened paraffin may cause structural disturbances, specially in soft soils. In addition, paraffin becomes brittle and cracks. Therefore, the use of paraffin alone for storage, or to seal the ends of samples transported or stored in tubes, is not recommended. Sealing is best accomplished by the use of microcrystalline wax alone or a mixture of 50 percent microcrystalline wax and 50 percent paraffin, both of which are not subject to cracking.

Storage of undisturbed samples (in or out of tubes) for long periods of time under any condition is not recommended. Storage of samples for more than 30 days may substantially alter strength and consolidation properties of the samples. Laboratory data obtained from these samples should be evaluated carefully.

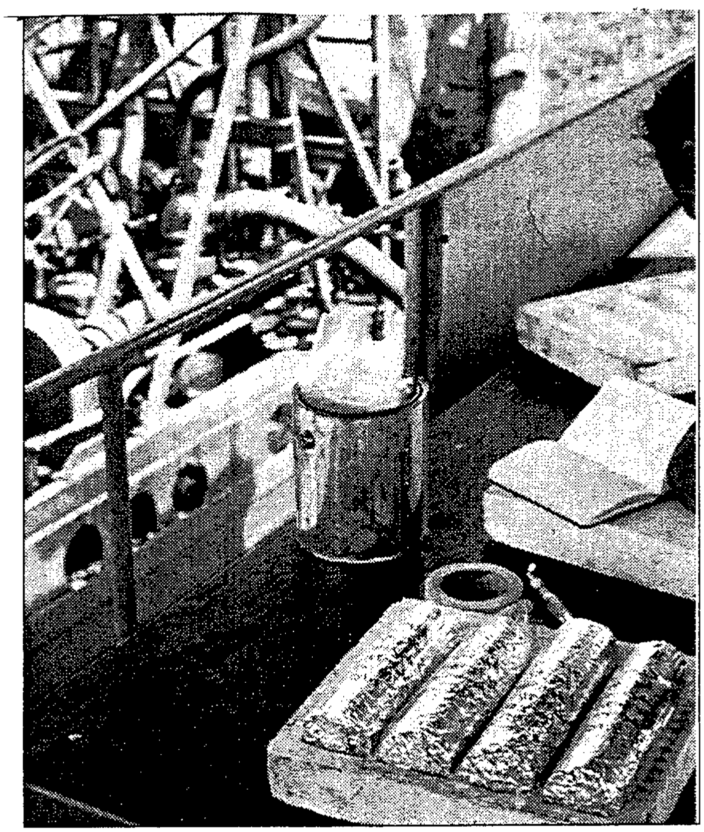


Figure 3-15: Extracted Sample Transportation and Storage.

3.2 EXPLORATION OF ROCK

The methods used for exploration and investigation of rock include:

- Drilling
- Exploration pits (test pits)
- Geologic mapping
- Geophysical methods

Core drilling which is used to obtain intact samples of rock for testing purposes and for assessing rock quality and structure, is the primary investigative method. Test pits, non-core drilling and geophysical methods are often used to identify the top of rock.

Geophysical methods may also be used to obtain information on the physical properties of the rock mass for engineering purposes. Finally, geologic mapping of rock exposures or outcrops provides a means for assessing the composition and discontinuities of rock strata on a large scale which may be valuable for many engineering applications particularly rock slope design.

This chapter contains a discussion of drilling and geologic mapping; geophysical methods are discussed in section 5.7.

3.2.1 Rock Drilling and Sampling

Where borings must extend into weathered and unweathered rock formations, rock drilling and sampling procedures are required. This section provides an abbreviated discussion of rock drilling and sampling methods. The use of ISRM (International Society for Rock Mechanics) Commission on Standardization of Laboratory and Field Tests (1978, 1981) guidelines are suggested for additional guidance in rock drilling and sampling and in logging rock cores.

Defining the top of rock from drilling operations can be difficult, especially where large boulders occur, below irregular residual soil profiles and in karstic terrain. In all cases, the determination of the top of rock must be done with care, recognizing that miscalculated rock excavation volume or erroneous pile length can be specified as a result of improper identification of the top of rock. As per ASTM D 2113, core drilling procedures are used when formations are encountered that are too hard to be sampled by soil sampling methods. A penetration of 25 mm or less by a 51 mm diameter split-barrel sampler following 50 blows using standard penetration energy or other criteria established by the geologist or engineer should indicate that soil sampling methods are not applicable and rock drilling or coring is required. Geophysical methods can be used to assist evaluation of the top of rock elevations.

3.2.2 Non-Core (Destructive) Drilling

Non-core rock drilling is a relatively quick and inexpensive means of advancing a boring which can be considered when an intact rock sample is not required. Non-core drilling is typically used for determining the top of rock and is useful in solution cavity identification in karstic terrain. Types of non-core drilling include air-track drilling, down-the-hole percussive drilling, rotary tricone (roller bit) drilling, rotary drag bit drilling, and augering with carbide-tipped bits in very soft rocks. Drilling fluid may be water, mud, foam, or compressed air. Caution should be exercised when using these methods to define the top of soft rock since drilling proceeds rapidly, and cuts weathered and soft rock easily, frequently misrepresenting the top of rock for elevation or pile driving applications.

Because intact rock samples are not recovered in non-core drilling, it is particularly important for the field supervisor to carefully record observations during drilling. The following information pertaining to drilling characteristics should be recorded in the remarks section of the boring log:

- Penetration rate or drilling speed in minutes per 0.3 meter
- Dropping of rods
- Changes in drill operation by driller (down pressures, rotation speeds, etc.)
- Changes in drill bit condition
- Unusual drilling action (chatter, bouncing, binding, etc.)
- Loss of drilling fluid, color change, or change in drilling pressure

3.2.3 Types of Core Drilling

A detailed discussion of diamond core drilling is presented in AASHTO T 225 and ASTM D 2113.

Core barrels (shown in Figures 3-16a,b,c) may be single-tube, double-tube, or triple-tube. Table 3-4 presents various types of core barrels available on the market. The minimum standard is a double-tube core barrel, which offers better recovery by isolating the rock core from the drilling fluid stream. The inner tube can be rigid or fixed to the core barrel head and rotate around the core or it can be mounted on roller bearings which allow the inner tube to remain stationary while the outer tube rotates. The second or swivel type core barrel is less disturbing to the core as it enters the inner barrel and is useful in coring fractured and friable rock. In some regions only triple tube core barrels are used in rock coring. In a multi-tube system, the inner tube may be longitudinally split to allow observation and removal of the core with reduced disturbance.

TABLE 3-4
DIMENSIONS OF CORE SIZES
(Christensen Dia-Min Tools, Inc.)

Size	Diameter of Core (mm)	Diameter of Borehole (mm)
EX,EXM	21.5	37.7
EWD3	21.2	37.7
AX	30.1	48.0
AWD4, AWD3	28.9	48.0
AWM	30.1	48.0
AQ Wireline, AV	27.1	48.0
BX	42.0	59.9
BWD4, BWD3	41.0	59.9
BXB Wireline, BWC3	36.4	59.9
BQ Wireline, BV	36.4	59.9
NX	54.7	75.7
NWD4,NWD3	52.3	75.7
NXB Wireline, NWC3	47.6	75.7
NQ Wireline, NV	47.6	75.7
HWD4	61.1	92.7
HXB Wireline, HWD3	61.1	92.7
HQ Wireline	63.5	96.3
CP, PQ Wireline	85.0	122.6

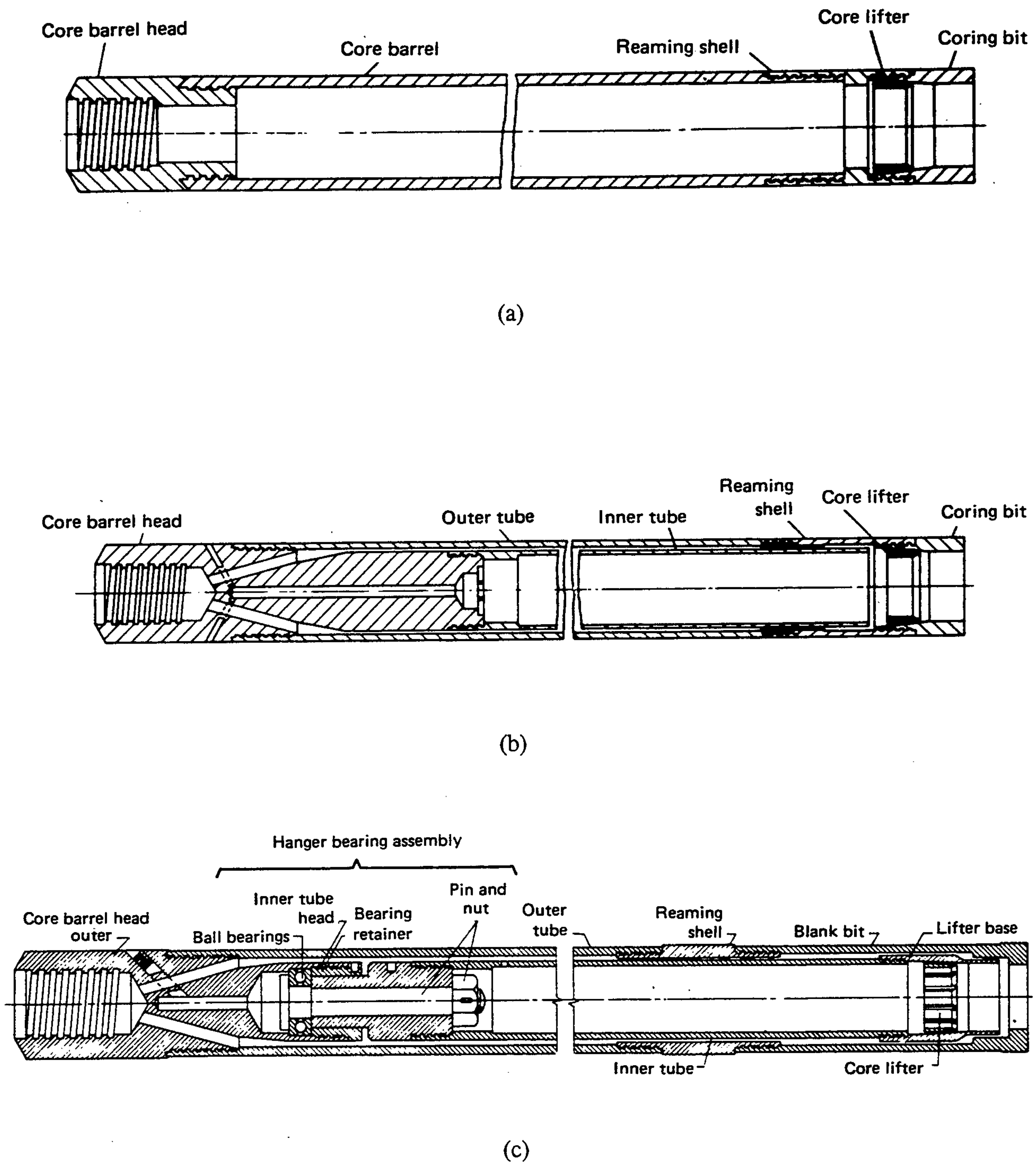


Figure 3-16: (a) Single Tube Core Barrel, (b) Rigid Type Double Tube Core Barrel (c) Swivel Type Double Tube Core Barrel, Series "M" with Ball Bearings. (Courtesy of Sprague & Henwood, Inc.)

Rock coring can be accomplished with either conventional or wireline equipment. With conventional drilling equipment, the entire string of rods and core barrel are brought to the surface after each core run to retrieve the rock core. Wireline drilling equipment allows the inner tube to be uncoupled from the outer tube and raised rapidly to the surface by means of a wire line hoist. The main advantage of wireline drilling over conventional drilling is the increased drilling production resulting from the rapid removal of the core from the hole which, in turn, decreases labor costs. It also provides improved quality of recovered core, particularly in soft rock, since this method avoids rough handling of the core barrel during retrieval of the barrel from the borehole and when the core barrel is opened. (Drillers often hammer on the core barrel to break it from the drill rods and to open the core barrel, causing the core to break.) Wireline drilling can be used on any rock coring job, but typically, it is used on projects where bore holes are greater than 25 m deep and rapid removal of the core from the hole has a greater effect on cost.

Although NX is the size most frequently used for engineering explorations, larger and smaller sizes are in use. Generally, a larger core size will produce greater recovery and less mechanical breakage. Because of their effect on core recovery, the size and type of coring equipment used should be carefully recorded in the appropriate places on the boring log.

The length of each core run should be limited to 3 m maximum. Core run lengths should be reduced to 1.5 m, or less, just below the rock surface and in highly fractured or weathered rock zones. Shorter core runs often reduce the degree of damage to the core and improve core recovery in poor quality rock.

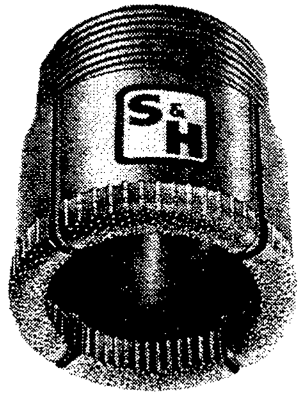
Coring Bits

The coring bit is the bottommost component of the core barrel assembly. It is the grinding action of this component that cuts the core from the rock mass. Three basic categories of bits are in use: diamond, carbide insert, and sawtooth. Figure 3-17 shows various types of coring bits. Coring bits are generally selected by the driller and are often approved by the geotechnical engineer. Bit selection should be based on general knowledge of drill bit performance for the expected formations and the proposed drilling fluid.

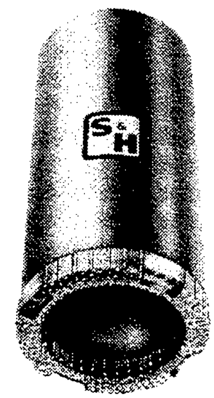
Diamond coring bits which may be of surface set or impregnated-diamond type are the most versatile since they can produce high-quality cores in rock materials ranging from soft to extremely hard. Compared to other types, diamond bits in general permit more rapid coring and as noted by Hvorslev (1949), exert lower torsional stresses on the core. Lower torsional stresses permit the retrieval of longer cores and cores of small diameter. The wide variation in the hardness, abrasiveness, and degree of fracturing encountered in rock has led to the design of bits to meet specific conditions known to exist or encountered at given sites. Thus, wide variations in the quality, size, and spacing of diamonds, in the composition of the metal matrix, in the face contour, and in the type and number of waterways are found in bits of this type. Similarly, the diamond content and the composition of the metal matrix of impregnated bits are varied to meet differing rock conditions.

Carbide bits use tungsten carbide in lieu of diamonds and are of several types. Two types, the standard and the pyramid carbide bits are shown in Figure 3-17 c and d. Bits of this type are used to core soft to medium-hard rock. They are less expensive than diamond bits. However, the rate of drilling is slower than with diamond bits.

Sawtooth bits consist of teeth cut into the bottom of the bit. The teeth are faced and tipped with a hard metal alloy such as tungsten carbide to provide water resistance and thereby to increase the life of the bit. Although these bits are less expensive than diamond bits, they do not provide as high a rate of coring and do not have a salvage value. The saw tooth bit is used primarily to core overburden and very soft rock.

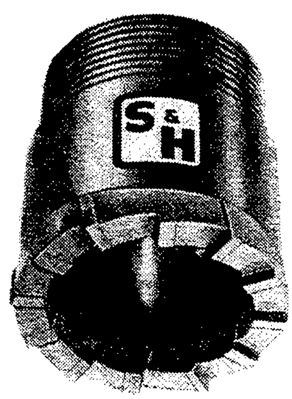


(a)

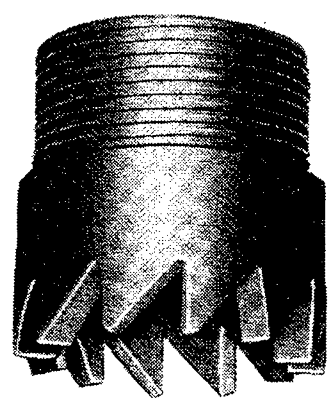


(b)

(c)



(d)



(e)

Figure 3-17: Coring Bits: (a) Diamond with Conventional Waterways, (b) Diamond with Bottom-Discharge Waterways, (c) Carbide Insert - Pyramid Type, (d) Carbide Insert - Blade Type, (e) Sawtooth. (Courtesy of Sprague & Henwood, Inc. and Acker Drill Co., Inc.)

An important feature of all bits which should be noted is the type of waterways provided in the bits for passage of drilling fluid. Bits are available with so-called "conventional" waterways, which are passages cut on the interior face of the bit (Figure 3-17a), or with bottom discharge waterways, which are internal and discharge at the bottom face of the bit behind a metal skirt separating the core from the discharge fluid (Figure 3-17b). Bottom discharge bits should be used when coring soft rock or rock having soil-filled joints to prevent erosion of the core by the drilling fluid before the core enters the core barrel.

Drilling Fluid

In many instances, clear water is used as the drilling fluid in rock coring. If drilling mud is required to stabilize collapsing holes or to seal zones when there is loss of drill water, the design engineer, the geologist and the geotechnical engineer should be notified to confirm that the type of drilling mud is acceptable. Drilling mud will clog open joints and fractures, which adversely affects permeability measurements and piezometer installations. Drilling fluid should be contained in a settling basin to remove drill cuttings and to allow recirculation of the fluid. Generally, drilling fluids can be discharged onto the ground surface. However, special precautions or handling may be required if the material is contaminated with oil or other substances and may require disposal off site. Water flow over the ground surface should be avoided, as much as possible.

3.2.4 Observation During Core Drilling

Drilling Rate/Time

The drilling rate should be monitored and recorded on the boring log in the units of minutes per 0.3 m. Only time spent advancing the boring should be used to determine the drilling rate.

Core Photographs

Cores in the split core barrel should be photographed immediately upon removal from the borehole. A label should be included in the photograph to identify the borehole, the depth interval and the number of the core runs. It may be desirable to get a "close-up" of interesting features in the core. Wetting the surface of the core using a spray bottle and/or sponge prior to photographing will often enhance the color contrasts of the core.

A tape measure or ruler should be placed across the top or bottom edge of the box to provide a scale in the photograph. The tape or ruler should be at least 1 meter long, and it should have relatively large, high contrast markings to be visible in the photograph.

A color bar chart is often desirable in the photograph to provide indications of the effects of variation in film age, film processing, and the ambient light source. The photographer should strive to maintain uniform light conditions from day to day, and those lighting conditions should be compatible with the type of film selected for the project.

Rock Classification

See Section 4.7 for a discussion of rock classification and other information to be recorded for rock core.

Recovery

The core recovery is the length of rock core recovered from a core run, and the recovery ratio is the ratio of the length of core recovered to the total length of the core drilled on a given run, expressed as either a fraction or a percentage. Core length should be measured along the core centerline. When the recovery is less than the length of the core run, the non-recovered section should be assumed to be at the end of the run unless there is reason to suspect otherwise (e.g., weathered zone, drop of rods, plugging during drilling, loss of fluid, and rolled or recut pieces of core). Non-recovery should be marked as NCR (no core recovery) on the boring log, and entries should not be made for bedding, fracturing, or weathering in that interval.

Recoveries greater than 100 percent may occur if core that was not recovered during a run is subsequently recovered in a later run. These should be recorded as such; adjustments to data should not be made in the field.

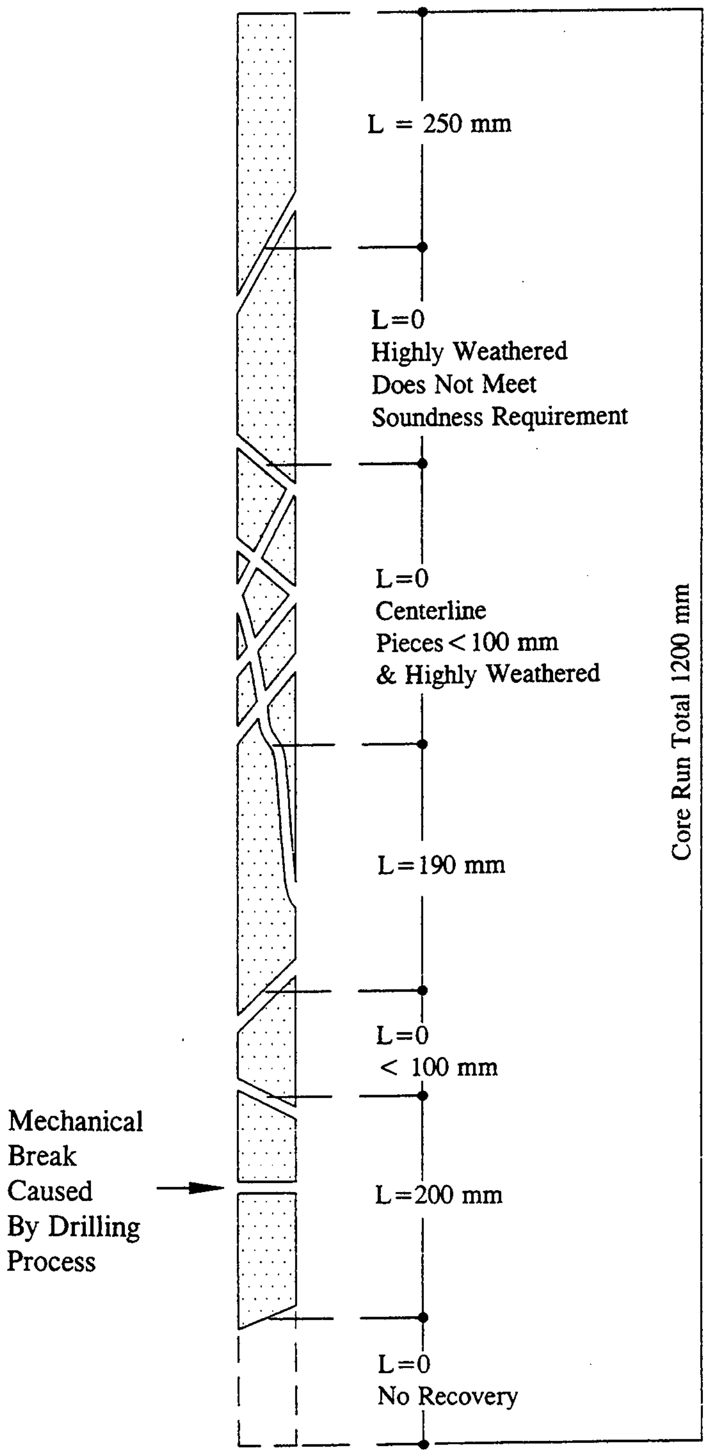
Rock Quality Designation (RQD)

The RQD is a modified core recovery percentage in which the lengths of all pieces of sound core over 100 mm long are summed and divided by the length of the core run. The correct procedure for measuring RQD is illustrated in Figure 3-18. The RQD is an index of rock quality in that problematic rock that is highly weathered, soft, fractured, sheared, and jointed typically yields lower RQD values. Thus, RQD is simply a measurement of the percentage of "good" rock recovered from an interval of a borehole. It should be noted that the original correlation for RQD (Rock Quality Designation) reported by Deere (1963) was based on measurements made on NX-size core. Experience in recent years reported by Deere and Deere (1989) indicates that cores with diameters both slightly larger and smaller than NX may be used for computing RQD. The wire line cores using NQ, HQ, and PQ are considered acceptable. The smaller BQ and BX sizes are discouraged because of more potential for core breakage and loss.

Length Measurements of Core Pieces

The same piece of core could be measured three ways: along the centerline, from tip to tip, or along the fully circular barrel section (Figure 3-19). The recommended procedure is to measure the core length along the centerline. This method is advocated by the International Society for Rock Mechanics (ISRM), Commission on Standardization of Laboratory and Field Tests (1978, 1981). The centerline measurement is preferred because: (1) it results in a standardized RQD that is not dependent on the core diameter, and (2) it avoids unduly penalizing of the quality of rock mass for cases where the fractures parallel the borehole and are cut by a second set.

Core breaks caused by the drilling process should be fitted together and counted as one piece. Drilling breaks are usually evidenced by rough fresh surfaces. For schistose and laminated rocks, it is often difficult to discern the difference between natural breaks and drilling breaks. When in doubt about a break, it should be considered as natural in order to be conservative in the calculation of RQD for most uses. This practice would not be conservative when the RQD is used as part of a ripping or dredging estimate.



$$RQD = \frac{\sum \text{Length of Sound Core Pieces} > 100\,\text{mm}}{\text{Total Core Run Length}}$$

$$RQD = \frac{250 + 190 + 200}{1200} \times 100\%$$

$RQD = 53\%$ (Fair)

Rock Quality Description

RQD (Rock Quality Designation)	Description of Rock Quality
0 - 25%	Very Poor
25 - 50%	Poor
50 - 75%	Fair
75 - 90%	Good
90 - 100%	Excellent

Figure 3-18: Modified Core Recovery as an Index of Rock Quality.

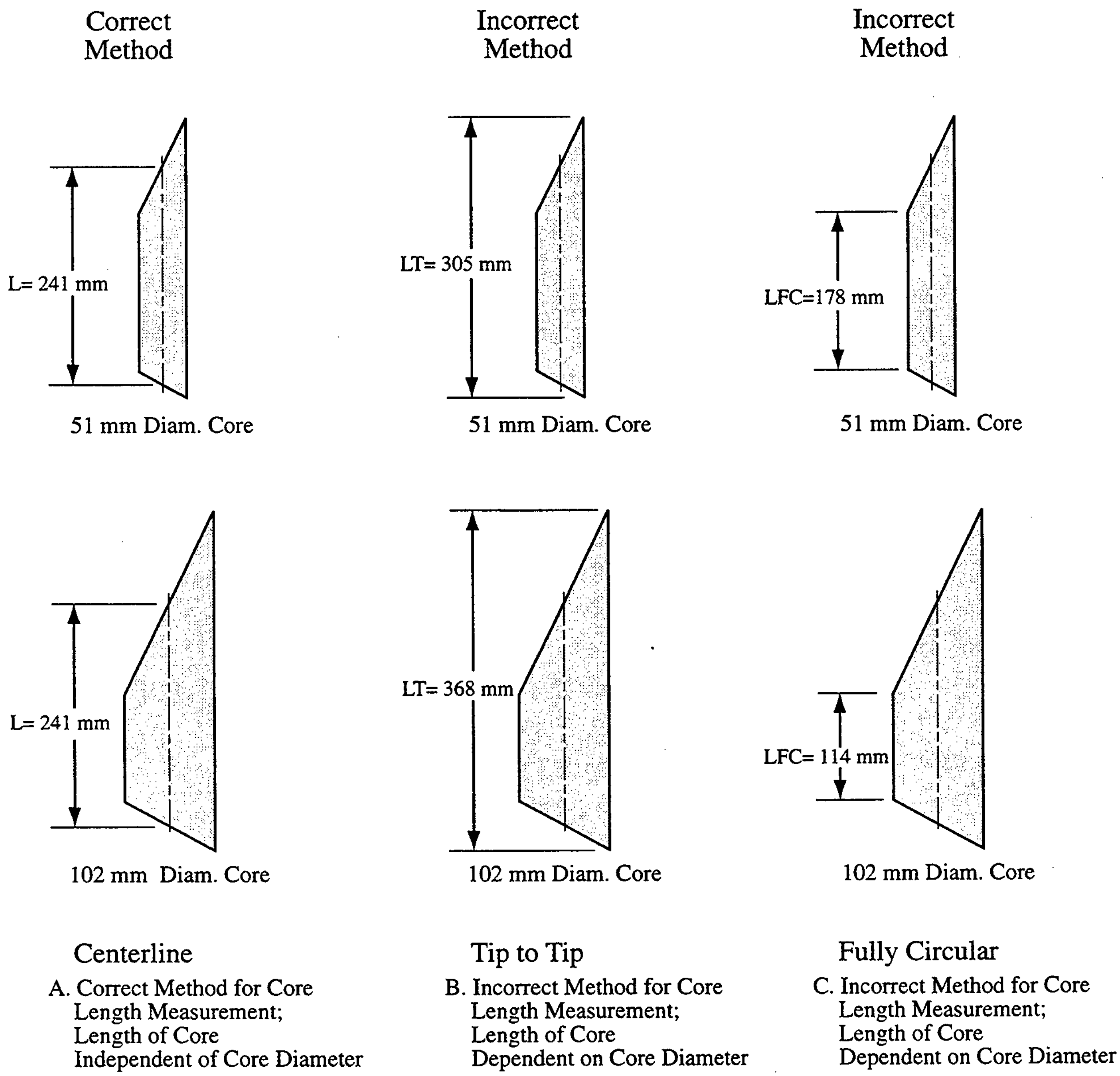


Figure 3-19: Length Measurement of Core for RQD Determination.

Assessment of Soundness

Pieces of core which are not "hard and sound" should not be counted for the RQD even though they possess the requisite 100 mm length. The purpose of the soundness requirement is to downgrade the rock quality where the rock has been altered and weakened either by agents of surface weathering or by hydrothermal activity. Obviously, in many instances, a judgment decision must be made as to whether or not the degree of chemical alteration is sufficient to reject the core piece.

One commonly used procedure is not to count a piece of core if there is any doubt about its meeting the soundness requirement (because of discolored or bleached grains, heavy staining, pitting, or weak grain boundaries). This procedure may unduly penalize the rock quality, but it errs on the side of conservatism. A second procedure which occasionally has been used is to include the altered rock within the RQD summed percentage, but to indicate by means of an asterisk (RQD*) that the soundness requirements have not been met. The advantage of the method is that the RQD* will provide some indication of the rock quality with respect to the degree of fracturing, while also noting its lack of soundness.

Drilling Fluid Recovery

The loss of drilling fluid during the advancement of a boring can be indicative of the presence of open joints, fracture zones or voids in the rock mass being drilled. Therefore, the volumes of fluid losses and the intervals over which they occur should be recorded. For example, "no fluid loss" means that no fluid was lost except through spillage and filling the hole. "Partial fluid loss" means that a return was achieved, but the amount of return was significantly less than the amount being pumped in. "Complete water loss" means that no fluid returned to the surface during the pumping operation. A combination of opinions from the field personnel and the driller on this matter will result in the best estimate.

Core Handling and Labeling

Rock cores from geotechnical explorations should be stored in structurally sound core boxes made of wood or corrugated waxed cardboard (Figure 3-20). Wooden boxes should be provided with hinged lids, with the hinges on the upper side of the box and a latch to secure the lid in a closed position.

Cores should be handled carefully during transfer from barrel to box to preserve mating across fractures and fracture-filling materials. Breaks in core that occur during or after the core is transferred to the core box should be refitted and marked with three short parallel lines across the fracture trace to indicate a mechanical break. Breaks made to fit the core into the core box and breaks made to examine an inner core surface should be marked as such. These deliberate breaks should be avoided unless absolutely necessary.

Cores should be placed in the boxes from left to right, top to bottom. When the upper compartment of the box is filled, the next lower (or adjoining) compartment (and so on until the box is filled) should be filled, beginning in each case at the left-hand end. The depths of the top and bottom of the core and each noticeable gap in the formation should be marked by a clearly labeled wooden spacer block.

If there is less than 100 percent core recovery for a run, a cardboard tube spacer of the same length as the core loss should be placed in the core box either at the depth of core loss, if known, or at the bottom of the run. The depth of core loss, if known, or length of core loss should be marked on the spacer with a black permanent marker.

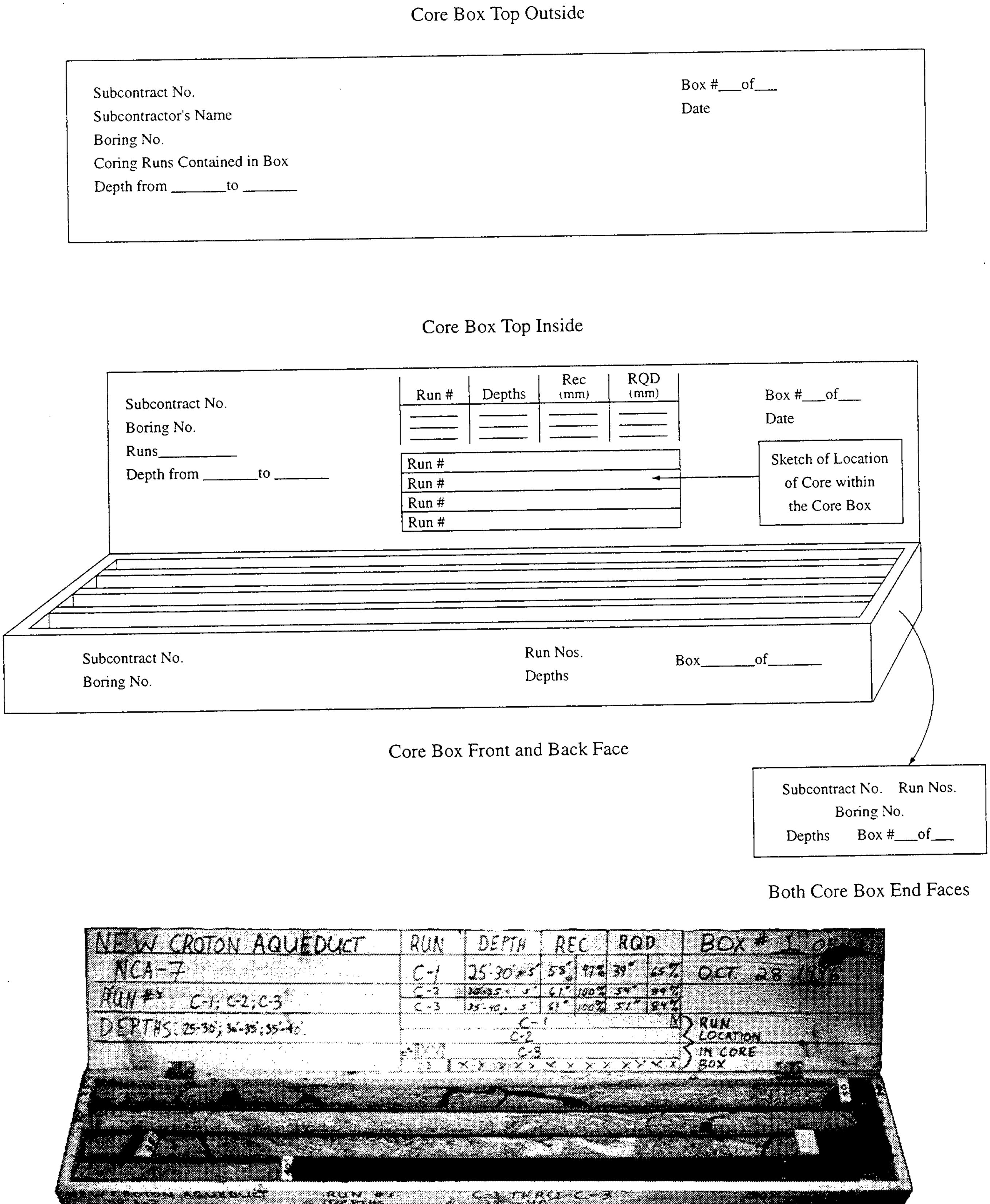


Figure 3-20: Core Box and Labeling.

The core box labels should be completed using an indelible black marking pen. An example of recommended core box markings is given in Figure 3-20. The core box lid should have identical markings both inside and out, and both exterior ends of the box should be marked as shown.

For angled borings, depths marked on core boxes and boring logs should be those measured along the axis of the boring. The angle and orientation of the boring should be noted on the core box and the boring log.

Care and Preservation of Rock Samples

A detailed discussion of sample preservation and transportation is presented in ASTM D 5079. Four levels of sample protection are identified:

- Routine care
- Special care
- Soil-like care
- Critical care

Most geotechnical explorations will require routine care in placing rock core in core boxes. ASTM D 5079 suggests enclosing the core in a loose-fitting polyethylene sleeve prior to placing the core in the core box.

Special care is considered appropriate if the moisture state of the rock core (especially shale, claystone and siltstone) and the corresponding properties of the core may be affected by exposure. This same procedure can also apply if it is important to maintain fluids other than water in the sample. Critical care is needed to protect samples against shock and vibration or variations in temperature, or both. For soil-like care, samples should be treated as indicated in ASTM D 4220.

3.2.5 Geologic Mapping

Geologic mapping is briefly discussed here, but is more fully described in Module 5 (Rock Slopes). Geologic mapping is the systematic collection of local, detailed geologic data, and, for engineering purposes, is used to characterize and document the condition of a rock mass or outcrop. The data derived from geologic mapping is a portion of the data required for design of a cut slope or for stabilization of an existing slope. Geologic mapping can often provide more extensive and less costly information than drilling. The guidelines presented are intended for rock and rock-like materials. Soil and soil-like materials, although occasionally mapped, are not considered in this section.

Qualified personnel trained in geology or engineering geology should perform the mapping or provide supervision and be responsible for the mapping activities and data collection. The first step in geologic mapping is to review and become familiar with the local and regional geology from published and non-published reports, maps and investigations. The mapping team should be knowledgeable of the rock units and structural and historical geologic aspects of the area. A team approach (minimum of two people, the "buddy system") is recommended for mapping as a safety precaution when mapping in isolated areas.

Procedures for mapping are outlined in an FHWA Manual (1989) on rock slope design, excavation and stabilization and in ASTM D 4879.

The first reference describes the parameters to be considered when mapping for cut slope design, which include:

- Discontinuity type
- Discontinuity orientation
- Discontinuity in filling
- Surface properties
- Discontinuity spacing
- Persistence
- Other rock mass parameters

These parameters can be easily recorded on a structural mapping coding form shown in Figure 3-21(a) and 3-21 (b). ASTM D 4879 also describes similar parameters and presents commonly used geologic symbols for mapping purposes. It also presents a suggested report outline. Presentation of discontinuity orientation data can be graphically plotted using stereographic projections. These projections are very useful in rock slope stability analyses. Chapter 3 (Graphical presentation of geological data) in the FHWA manual cited above describes the stereographic projection methods in detail.

3.3 BORING CLOSURE

All borings should be properly closed at the completion of the field exploration. This is typically required for safety considerations and to prevent cross contamination of soil strata and groundwater. Boring closure is particularly important for tunnel projects since an open borehole exposed during tunneling may lead to uncontrolled inflow of water or escape of compressed air.

In many parts of the country, methods to be used for the closure of boreholes are regulated by state agencies. National Cooperative Highway Research Program Report No. 378 (1995) titled "Recommended Guidelines for Sealing Geotechnical Holes" contains extensive information on sealing and grouting. The regulations in general, require that any time groundwater or contamination is encountered the borehole be grouted using a mixture of powdered bentonite, portland cement and potable water. Some state agencies require grouting of all boreholes exceeding a certain depth. The geotechnical engineer and the field supervisor should be knowledgeable about local requirements prior to commencing the borings.

It is good practice to grout all boreholes. Holes in pavements and slabs should be filled with quick setting concrete, or with asphaltic concrete, as appropriate. Backfilling of boreholes is generally accomplished using a grout mixture . The grout mix is normally pumped though drill rods or other pipes inserted into the borehole. In boreholes filled with water or other drilling fluids the tremied grout will displace the drill fluid. Provisions should be made to collect and dispose of all displaced drill fluid and waste grout.

Exploration pits can, generally, be backfilled with the spoils generated during the excavation. The backfilled material should be compacted to avoid excessive future settlements. Tampers or rolling equipment may be used to facilitate compaction of the backfill.

3.4 SAFETY GUIDELINES FOR GEOTECHNICAL BORINGS

All field personnel, including geologists, engineers, technicians, and drill crews, should be familiar with the general health and safety procedures, as well as any additional requirements of the project or governing agency.

Typical safety guidelines for drilling into soil and rock are presented in Appendix A. Minimum protective gear for all personnel should include hard hat, safety boots, eye protection, and gloves.

GENERAL INFORMATION

Subdivision [ ] Km [ ] Date Day [ ] Month [ ] Year [ ] Inspector [ ]

Discontinuity data
Sheet No. [ ] of [ ]

NATURE AND ORIENTATION OF DISCONTINUITY

Station or No.	Type	Dip	Dip direction	Persistence	Aperture	Nature of filling	Strength of filling	Surface Roughness	Trend of lineation	Waviness wavelength	Waviness amplitude	Water/ Flow	Remarks

Type

0. Fault zone
1. Fault
2. Joint
3. Cleavage
4. Schistosity
5. Shear
6. Fissure
7. Tension crack
8. Foliation
9. Bedding

Persistence

1. Very low persistence <1 m
2. Low Persistence 1-3 m
3. Medium persistence 3-10 m
4. High persistence 10-20 m
5. Very high persistence >20 m

Aperture

1. Very tight (<0.1 mm)
2. Tight (0.1-0.25 mm)
3. Partly open (0.25-0.5 mm)
4. Open (0.5-2.5 mm)
5. Moderately wide (2.5-10 mm)
6. Wide (>10 mm)
7. Very wide (1-10 cm)
8. Extremely wide (10 - 100 cm)
9. Cavernous

Nature of filling

1. Clean
2. Surface staining
3. Non-cohesive
4. Inactive clay or clay matrix
5. Swelling clay or clay matrix
6. Cemented
7. Chlorite, talc, or gypsum
8. Others - specify

Compressive strength of infilling

		MPa
1.	Very strong rock	>200
2.	Strong rock	100-200
3.	Moderately strong rock	50-100
4.	Moderately weak rock	25-50
5.	Very weak rock	1-25
6.	Very stiff soil	0.6-1.0
7.	Stiff soil	0.15-0.6
8.	Firm soil	0.08-0.15
9.	Soft soil	0.04-0.08
10.	Very soft soil	<0.04

Roughness

1. Rough (or irregular), stepped
2. Smooth, stepped
3. Slickensided stepped
4. Rough (or irregular), undulating
5. Smooth, undulating
6. Slickensided, undulating
7. Rough (or irregular), planar
8. Smooth, planar
9. Slickensided

Water Flow (Infilled)

Seepage Rating	Description
I	The discontinuity is very tight and dry; water flow along it does not appear possible.
II	The discontinuity is dry with no evidence of water flow.
III	The discontinuity is dry but shows evidence of water flow, i.e. rust staining, etc.
IV	The discontinuity is damp but no free water is present.
V	The discontinuity shows seepage, occasional drops of water, but no continuous flow.
VI	The discontinuity shows a continuous flow of water (Estimate l/min and describe pressure, i.e. low, medium, high).

Water Flow (Filled)

W1 The filling materials are heavily consolidated and dry; significant flow appears unlikely due to very low permeability.
W2 The filling materials are damp, but no free water is present.
W3 The filling materials are wet; occasional drops of water.
W4 The filling materials show signs of outwash, continuous flow of water (estimate liters/minute).
W5 The filling materials are washed out locally; considerable water flow along out-wash channels (estimate liters/minute and describe pressure, i.e. low, medium, high).

Figure 3-21: (a) Structural Mapping Coding Form for Discontinuity Survey Data.

ROCK MASS DESCRIPTION

GENERAL INFORMATION

Subdivision | Km | Date: Day Month Year | Inspector

Locality Type

1. Natural exposure
2. Construction excavation
3. Trial pit
4. Trench
5. Adit
6. Tunnel

Slope Length

Slope Height

No. of supplementary sheets of discontinuity data

Sketch

Photograph

0. No
1. Yes

SLOPE STABILITY ASSESSMENT

Inspection Rating

1. **Urgent** - recent fall/visual evidence of significant movement - hazard
2. **Priority** - evidence of movement or change in conditions from previous years
3. **Observe** - identification of a specific area of potential instability
4. **OK** - no potential instability

Required Action

1. **Inspect** - inspection required within the new three months approximately - state time
2. **Immediate Work** - stabilization work of specific location required in current year - state time
3. **Slow Order** - traffic at restricted speed/stopped/watchman until stabilization work carried out
4. **1-5 Years** - possible stabilization - state time
5. **Long-term** - substantial stabilization program
6. **No Action**

Assessment of Site Conditions

1. Open fractures indicative of past movement.
2. Fractures oriented such that blocks could slide or topple on to the track.
3. Evidence of recent movement.
4. Probability that rockfall/slide would be of sufficient size to reach tracks and cause derailment.
5. Serious consequence of derailment (e.g. track on narrow bench or supported by retaining wall).

Remarks (consequences, stabilization, rockfalls, slide fence)

ROCK MATERIAL INFORMATION

Color

1. Light
2. Dark

1. Pinkish
2. Reddish
3. Yellowish
4. Brownish
5. Olive
6. Greenish
7. Bluish
8. Greyish

1. Pink
2. Red
3. Yellow
4. Brown
5. Olive
6. Green
7. Blue
8. White
9. Grey
0. Black

Grain Size

1. Very coarse (>60 mm)
2. Coarse (2-60 mm)
3. Medium (60 μ-20 mm)
4. Fine (2-60 μ)
5. Very fine (<2μ)

Compressive strength

	MPa
1. Very strong rock	>200
2. Strong rock	100-200
3. Moderately strong rock	50-100
4. Moderately weak rock	25-50
5. Very weak rock	1-25
6. Very stiff soil	0.6-1.0
7. Stiff soil	0.15-0.6
8. Firm soil	0.08-0.15
9. Soft Soil	0.04-0.08
10. Very soft soil	<0.04

Method of determining compressive strength

1. Measured
2. Assessed

Rock Type

Qualifying terms to decribe rock

ROCK MASS INFORMATION

Fabric

1. Blocky
2. Tabular
3. Columnar

Block size

1. Very large (>8 m³)
2. Large (0.2-8 m³)
3. Medium (0.008-0.2 m³)
4. Small (0.0002-0.008 m³)
5. Very small (<0.0002 m³)

State of weathering

1. Fresh
2. Slightly
3. Moderately
4. Highly
5. Completely
6. Residual soil

No. of major discontinuity sets

LINE SURVEYS TO DETERMINE DISCONTINUITY SPACINGS

	Plunge of line	Trend of line	Length of line (m)	No. of fractures	Spacing	Remarks
Line 1						
Line 2						
Line 3						

Discontinuity spacing

1. Extremely close (<20 mm)
2. Very close (20-60 mm)
3. Close (60-200 mm)
4. Moderate (200-600 mm)
5. Wide (600-2000 mm)
6. Very wide (2000-60000 mm)
7. Ext. Wide (>6000 mm)

Figure 3-21: (b) Structural Mapping Coding Form for Slope Assessment.

It is not unusual to encounter unknown or unexpected environmental problems during a site investigation. For example, discolored soils or rock fragments from prior spills, or contaminated groundwater may be detected. The geotechnical engineer and the field supervisor should attempt to identify possible contamination sources prior to initiating fieldwork. Based on this evaluation, a decision should be made whether a site safety plan should be prepared. Environmental problems can adversely affect investigation schedules and cost, and may require the obtaining of permits from State or Federal agencies prior to drilling or sampling.

At geotechnical exploration sites where unknown or unexpected contamination is found during the fieldwork, the following steps should be taken:

1. The field supervisor should immediately stop drilling and notify the geotechnical engineer. The field supervisor should identify the evidence of contamination, the depth of contamination, and the estimated depth to the water table (if known). If liquid-phase product is encountered (at or above the water table), the boring should be abandoned immediately and sealed with hydrated bentonite chips or grout.

2. The project manager should advise the environmental officer of the governing agency and decide if special health and safety protocol should be implemented. Initial actions may require demobilization from the site.

3.5 COMMON ERRORS BY DRILLERS

Drillers performance is commonly judged by the quantity of production rather than the quality of the borings and samples. Not surprisingly, similar problems develop throughout the country. All geotechnical engineers and field supervisors need to be trained to recognize these problems, and to assure that field information and samples are properly obtained. The following is a partial listing of common errors:

- Not properly cleaning slough and cuttings from the bottom of the bore hole. The driller should not be allowed to sample through slough. Preferably the driller should re-enter the boring and remove the slough before proceeding.

- In cohesionless soils, jetting should not be used to advance a split barrel sampler to the bottom of the boring.

- Poor sample recovery due to use of improper sampling equipment or procedures.

- When sampling soft or non-cohesive soils with thin wall tube samplers (i.e., Shelby tube) it may not be possible to recover an undisturbed sample because the sample will not stay in the barrel. The driller should be clearly instructed not to force recovery by overdriving the sampling barrel to grab a sample.

- Improper sample types or insufficient quantity of samples. The driller should be given clear instructions regarding the sample frequency and types of samples required. The field supervisor must keep track of the depth of the borings at all stages of the exploration to confirm proper sampling of the soil and/or rock formations.

- Improper hole stabilization. Rotary wash borings and hollow-stem auger borings below the groundwater level require a head of water to be maintained at the top of the casing/augers at all times. When the drill rods are withdrawn or as the hollow stem auger is advanced, this water level will tend to drop, and must be maintained by the addition of more drilling fluid. Without this precaution, the sides of the boring may collapse or the bottom of the boring may heave.

- Sampler rods lowered into the boring with pipe wrenches rather than hoisting plug. The rods may be inclined and the sampler can hit the boring walls, filling the sampler with debris.

- Improper procedures for performing Standard Penetration Tests. The field supervisor and driller must assure that the proper weight and hammer drop are being used, and that friction at the cathead and along any hammer guides is minimized.

CHAPTER 4.0
BORING LOG PREPARATION

4.1 GENERAL

The boring log is the basic record of almost every geotechnical exploration and provides a detailed record of the work performed and the findings of the investigation. The field log should be written or printed legibly, and should be kept as clean as is practical. All appropriate portions of the logs should be completed in the field prior to completion of the field exploration.

A wide variety of drilling forms are used by various agencies. The specific forms to be used for a given type of boring will depend on local practice. Typical boring log, core boring log and test pit log forms endorsed by the ASCE Soil Mechanics and Foundations Engineering Steering Committee are presented in Figures 4-1 through 4-3, respectively. A proposed legend for soil boring logs is presented in Figure 4-4 and a proposed legend for core boring logs is presented in Figure 4-5. This chapter presents guidelines for completion of the boring log forms, preparation of soil descriptions and classifications, and preparation of rock descriptions and classifications.

A boring log is a description of exploration procedures and subsurface conditions encountered during drilling, sampling and coring. Following is a brief list of items which should be included in the logs. These items are discussed in detail in subsequent sections:

- Topographic survey data including boring location and surface elevation, and bench mark location and datum, if available.
- An accurate record of any deviation in the planned boring locations.
- Identification of the subsoils and bedrock including density, consistency, color, moisture, structure, geologic origin.
- The depths of the various generalized soil and rock strata encountered.
- Sampler type, depth, penetration, and recovery.
- Sampling resistance in terms of hydraulic pressure or blows per depth of sampler penetration. Size and type of hammer. Height of drop.
- Soil sampling interval and recovery.
- Rock core run numbers, depths and lengths, core recovery, and Rock Quality Designation (RQD) measurements.
- Type of drilling operation used to advance and stabilize the hole.
- Comparative resistance to drilling.
- Loss of drilling fluid.
- Water level observations with remarks on possible variations due to tides, river level, etc.

Project: **Project Location:** **Project Number:**	**Log of Boring ___** Sheet 1 of ___

Date(s) Drilled	Logged By	Checked By
Drilling Method	Drill Bit Size/Type	Total Depth Drilled (meters)
Drill Rig Type	Drilled By	Hammer Weight/ Drop (N/m)
Apparent Groundwater Depth ____ m ATD ____ m after ____ hrs ____ m after ____ hrs		Surface Elevation (meters)
Comments	Borehole Backfill	Elevation Datum

Depth, meters	SAMPLES				MATERIAL DESCRIPTION and other remarks	Elevation, meters	Pocket Pen., kPa	Water Content, %	Liquid Limit	Plasticity Index	Other Tests
	Location	Type	Number	Sampling Resistance							
0											
1											
2											
3											
4											

Template: Proj ID: Printed:

Figure 4-1: Typical Boring Log Form.

Project: Project Location: Project Number:	**Log of Core Boring ___** Sheet 1 of ___

Date(s) Drilled	Logged By	Checked By
Drilling Method	Drill Bit Size/Type	Total Depth Drilled (meters)
Drill Rig Type	Drilled By	Inclination from Vertical/Bearing
Apparent Groundwater Depth ____ m ATD ____ m after ____ hrs ____ m after ____ hrs		Approx. Surface Elevation (meters)
Comments		Borehole Backfill

Depth, meters	Elevation, meters	ROCK CORE							MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES
		Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/ Number	Lithology					
0													
1													

Template: Proj ID: Printed:

Figure 4-2: Typical Core Boring Log.

Project: Project Location: Project Number:	**Log of Exploration Pit ___**

Date(s) Excavated	Logged By	Checked By
Approximate Length (meters)	Approximate Width (meters)	Approximate Depth (meters)
Excavation Equipment	Excavation Contractor	Approximate Pit Trend
Groundwater Level (meters)	Date Measured	Approx. Surface Elevation (meters)
Comments		

Depth, meters	Elevation, meters	Sample Type	and Number	Pocket Pen., kPa	Graphic Log	**MATERIAL DESCRIPTION** and other remarks	Water Content, %	Other Tests
0								
1								
2								
3								
4								

Template: Proj ID: Printed:

Figure 4-3: Typical Exploration Pit Log.

Project:
Project Location:
Project Number:

Key to Soil Symbols and Terms

Sheet 1 of 2

Depth, meters	SAMPLES Location	Type	Number	Sampling Resistance	MATERIAL DESCRIPTION and other remarks	Elevation, meters	Pocket Pen., kPa	Water Content, %	Liquid Limit	Plasticity Index	Other Tests
0					DESCRIPTIONS OF SAMPLER AND FIELD TEST CODES						
1		S	1	15	The number of blows (15) of a 63.6 Kgr hammer falling 750 mm used to drive a 50 mm O.D. split-barrel sampler for the last 300 mm of penetration.						
		S	2	50/150	Number of blows (50) used to drive the split-barrel a certain number of millimeters (150).						
2		P	3	1724	Thin-wall tube pushed hydraulically, using a certain pressure (1,724 kPa) to push the last 150 mm.						
					SAMPLER CODES P - Thin-wall tube sample. C - Denison or Pitcher-type core-barrel sample. Ps - Piston sample. A - Auger sample. BS - Bulk sample. SS - Standard spoon sample. CL - California liner sample.						
3		A	4								
4		NX - 65	5	40	BX - Rock cored with BX core barrel, which obtains a 41 mm-diameter core. NX - Rock cored with NX core barrel, which obtains a 53 mm-diameter core. 65 - Percentage (65) of rock core recovered. 40 - Rock Quality Designation (RQD) percentage (40).						
5		S			Sample recovered: indicated by blackened box in "Location" column.						
6		NR			Sample not recovered: indicated by vertical bar in "Location" column and "NR" (no recovery) in "Type" column.						
7					OTHER FIELD TEST DESIGNATIONS FV - Field vane shear test. PMT - Pressuremeter test. DMT - Dilatometer test. BHS - Borehole shear test.						

ABBREVIATIONS FOR "OTHER TESTS" COLUMN

- **C** - Consolidation and specific gravity tests.
- **D** - Maximum and minimum density.
- **DS** - Direct shear test.
- **G** - Specific gravity test.
- **K** - Permeability test.
- **M** - Mechanical (sieve or hydrometer) analysis.
- **T** - Triaxial compression test.
- **TV** - Torvane shear test.
- **U** - Unconfined compression test.
- **W** - Unit weight and natural moisture content.
- **X** - Special tests performed - see laboratory test results.

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Figure 4-4: Proposed Key to Boring Log (Continued on Page 4-6).

Project:	Key to Soil Symbols and Terms
Project Location:	Sheet 2 of 2
Project Number:	

TERMS DESCRIBING CONSISTENCY OR CONDITION

COARSE-GRAINED SOILS (major portion retained on No. 200 sieve): includes (1) clean gravels and sands and (2) silty or clayey gravels and sands. Condition is rated according to relative density as determined by laboratory tests or standard penetration resistance tests.

Descriptive Term	Relative Density	SPT Blow Count
Very loose	0 to 15%	< 4
Loose	15 to 35%	4 to 10
Medium dense	35 to 65%	10 to 30
Dense	65 to 85%	30 to 50
Very dense	85 to 100%	> 50

FINE-GRAINED SOILS (major portion passing on No. 200 sieve): includes (1) inorganic and organic silts and clays, (2) gravelly, sandy, or silty clays, and (3) clayey silts. Consistency is rated according to shearing strength, as indicated by penetrometer readings, SPT blow count, or unconfined compression tests.

Descriptive Term	Unconfined Compressive Strength, kPa	SPT Blow Count
Very soft	< 25	< 2
Soft	25 to 50	2 to 4
Medium stiff	50 to 100	4 to 8
Stiff	100 to 200	8 to 15
Very stiff	200 to 400	15 to 30
Hard	> 400	> 30

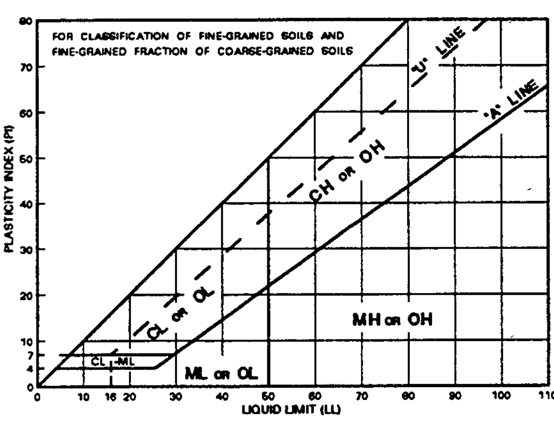
GENERAL NOTES

1. Classifications are based on the Unified Soil Classification System and include consistency, moisture, and color. Field descriptions have been modified to reflect results of laboratory tests where deemed appropriate.

2. Surface elevations are based on topographic maps and estimated locations.

3. Descriptions on these boring logs apply only at the specific boring locations and at the time the borings were made. They are not warranted to be representative of subsurface conditions at other locations or times.

Major Divisions			Group Symbols	Typical Names	Laboratory Classification Criteria	
Coarse-Grained Soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve) coarse-grained soils are classified as follows: Less than 5 percent ...... GW, GP, SW, SP; More than 12 percent ...... GM, GC, SM, SC; 5 to 12 percent ...... Borderline cases requiring dual symbols **	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3
			GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW
		Gravels with fines (Appreciable amount of fines)	GM* d / u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4 — Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-silt mixtures		Atterberg limits above "A" line or P.I. greater than 7
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3
			SP	Poorly-graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW
		Sands with fines (Appreciable amount of fines)	SM* d / u	Silty sands, sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4 — Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits above "A" line or P.I. greater than 7
Fine-Grained Soils (More than half of material is smaller than No. 200 sieve size)	Silts and Clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Plasticity Chart	
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			OL	Organic silts and organic silty clays of low plasticity		
	Silts and Clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts		
			CH	Inorganic clays of high plasticity, fat clays		
			OH	Organic clays of medium to high plasticity, organic silts		
Highly Organic Soils			Pt	Peat and other highly organic soils		



Plasticity Chart

Particle Size

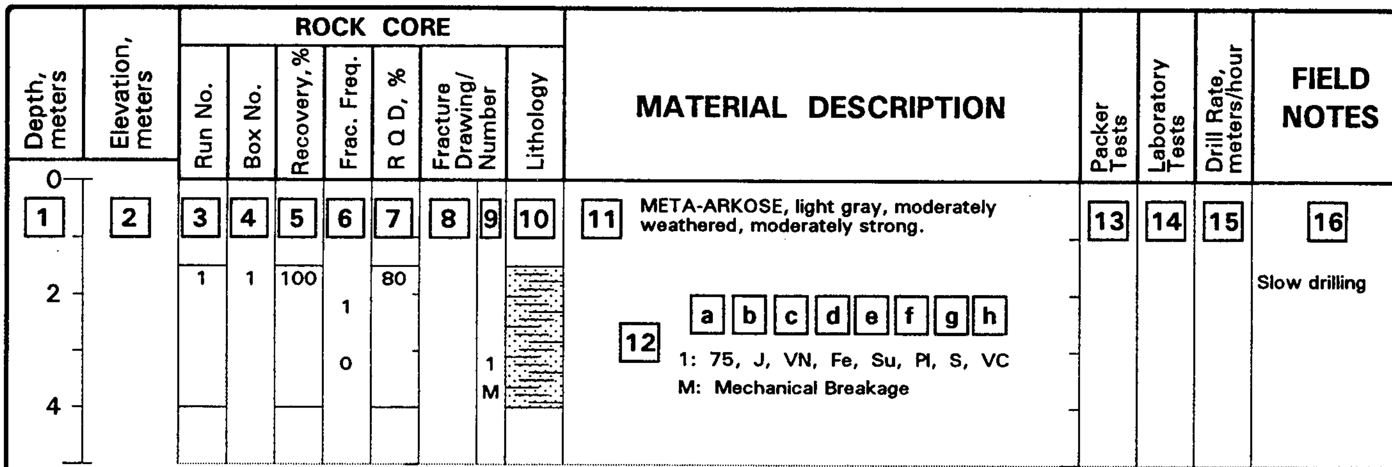
Material		Sieve size	mm
Silt or clay		< #200	< 0.074
Sand	Fine	#200 to #40	0.074 to 0.42
	Medium	#40 to #10	0.42 to 2.00
	Coarse	#10 to #4	2.00 to 4.76
Gravel	Fine	#4 to 3/4 in.	4.76 to 19.1
	Coarse	3/4 in. to 3 in.	19.1 to 76.2
Cobbles		3 in. to 12 in.	76.2 to 304.8
Boulders		12 in. to 36 in.	304.8 to 914.4

* Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg Limits: suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

** Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

Figure 4-4: Proposed Key to Boring Log.

Project: **Project Location:** **Project Number:**	**Key to Rock Core Log** Sheet 1 of 2



1	**Depth:**	Distance (in meters) from the collar of the borehole.
2	**Elevation:**	Elevation (in meters) from the collar of the borehole.
3	**Run No.:**	Number of the individual coring interval, starting at the top of bedrock.
4	**Box No.:**	Number of the core box which contains core from the corresponding run.
5	**Recovery:**	Amount (in percent) of core recovered from the coring interval; calculated as the length of core recovered divided by the length of the run.
6	**Frac. Freq.:**	(Fracture Frequency) The number of naturally occurring fractures in each foot of core; does not include mechanical breaks, which are considered to be induced by drilling.
7	**R Q D:**	(Rock Quality Designation) Amount (in percent) of intact core (pieces of sound core greater than 100 mm in length) in each coring interval; calculated as the sum of the lengths of intact core divided by the length of the core run.
8	**Fracture Drawing:**	Sketch of the naturally occurring fractures and mechanical breaks, showing the angle of the fractures relative to the cross-sectional axis of the core. "NR" indicates no recovery.
9	**Fracture Number:**	Location of each naturally occurring fracture (numbered) and mechanical break (labeled "M"). Naturally occurring fractures are described in Column 11 (keyed by number) using descriptive terms defined on the following page (Items a - h).
10	**Lithology:**	A graphic log presentation using symbols to represent differing rock types.
11	**Description:**	Lithologic description in this order: rock type, color, texture, grain size, foliation, weathering, strength, and other features; descriptive terms are defined on the following page. A detailed descriptive log of overburden materials is not necessarily provided.
12	**Discontinuity Description:**	Abbreviated description of fracture corresponding to number of naturally occurring fracture in Column 9 using terms defined on the following page (Items a - h).
13	**Packer Tests:**	A vertical line depicts the interval over which a packer test is performed.
14	**Laboratory Tests:**	A vertical line depicts the interval over which core has been removed for laboratory testing. Laboratory tests performed are indicated in Column 16.
15	**Drill Rate:**	Rate (in meters per hour) of penetration of drilling. "N/O" indicates rate not observed.
16	**Field Notes:**	Comments on drilling, including water loss, reasons for core loss, and use of drilling mud; also, laboratory tests performed on core.

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Figure 4-5: Proposed Key to Core Boring Log (Continued on Page 4-8).

Project: **Project Location:** **Project Number:**	**Key to Rock Core Log** Sheet 2 of 2

Depth, meters	Elevation, meters	ROCK CORE: Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/ Number	Lithology	MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES

KEY TO DESCRIPTIVE TERMS USED ON CORE LOGS

DISCONTINUITY DESCRIPTORS

a Dip of fracture surface measured relative to horizontal

b **Discontinuity Type:**
- F - Fault
- J - Joint
- Sh - Shear
- Fo - Foliation
- V - Vein
- B - Bedding

c **Discontinuity Width (millimeters):**
- W - Wide (12.5-50)
- MW - Moderately Wide (2.5-12.5)
- N - Narrow (1.25-2.5)
- VN - Very Narrow (<1.25)
- T - Tight (0)

d **Type of Infilling:**
- Cl - Clay
- Ca - Calcite
- Ch - Chlorite
- Fe - Iron Oxide
- Gy - Gypsum/Talc
- H - Healed
- No - None
- Py - Pyrite
- Qz - Quartz
- Sd - Sand

e **Amount of Infilling:**
- Su - Surface Stain
- Sp - Spotty
- Pa - Partially Filled
- Fi - Filled
- No - None

f **Surface Shape of Joint:**
- Wa - Wavy
- Pl - Planar
- St - Stepped
- Ir - Irregular

g **Roughness of Surface:**
- Slk - Slickensided [surface has smooth, glassy finish with visual evidence of striations]
- S - Smooth [surface appears smooth and feels so to the touch]
- SR - Slightly Rough [asperities on the discontinuity surfaces are distinguishable and can be felt]
- R - Rough [some ridges and side-angle steps are evident; asperities are clearly visible, and discontinuity surface feels very abrasive]
- VR - Very Rough [near-vertical steps and ridges occur on the discontinuity surface]

h **Discontinuity Spacing (meters):**
- EW - Extremely Wide (>20)
- W - Wide (7-20)
- M - Moderate (2.5-7)
- C - Close (0.7-2.5)
- VC - Very Close (<0.7)

ROCK WEATHERING / ALTERATION

Description	Recognition
Residual Soil	Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is not apparent; material can be easily broken by hand
Completely Weathered/Altered	Original minerals of rock have been almost entirely decomposed to secondary minerals, minerals, although original fabric may be intact; material can be granulated by hand
Highly Weathered/Altered	More than half of the rock is decomposed; rock is weakened so that a minimum 50-mm-diameter sample can be broken readily by hand across rock fabric
Moderately Weathered/Altered	Rock is discolored and noticeably weakened, but less than half is decomposed; a minimum 50-mm-diameter sample cannot be broken readily by hand across rock fabric
Slightly Weathered/Altered	Rock is slightly discolored, but not noticeably lower in strength than fresh rock
Fresh	Rock shows no discoloration, loss of strength, or other effect of weathering/alteration

ROCK STRENGTH

Description	Recognition	Approximate Uniaxial Compressive Strength (kPa)
Extremely Weak Rock	Can be indented by thumbnail	250 - 1,000
Very Weak Rock	Can be peeled by pocket knife	1,000 - 5,000
Weak Rock	Can be peeled with difficulty by pocket knife	5,000 - 25,000
Medium Strong Rock	Can be indented 5 mm with sharp end of pick	25,000 - 50,000
Strong Rock	Requires one hammer blow to fracture	50,000 - 100,000
Very Strong Rock	Requires many hammer blows to fracture	100,000 - 250,000
Extremely Strong Rock	Can only be chipped with hammer blows	> 250,000

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Figure 4-5: Proposed Key to Core Boring.

- The date and time that the borings are started, completed, and of water level measurements.
- Closure of borings.

Boring logs provide the basic information for the selection of test specimens. They provide background data on the natural condition of the formation, on the ground water elevation, appearance of the samples, and the soil or rock stratigraphy at the boring location, as well as areal extent of various deposits or formations. Data from the boring logs are combined with laboratory test results to identify subgrade profiles showing the extent and depth of various materials at the subject site. Soil profiles showing the depth and the location of various types of materials and ground water elevations are plotted for inclusion in the geotechnical engineer's final report and in the plans and specifications. Detailed boring logs including the results of laboratory tests are included in the text of the report.

4.2 PROJECT INFORMATION

The top of each boring log provides a space for project specific information: name or number of the project, location of the project, drilling contractor (if drilling is contracted out), type of drilling equipment, date and time of work, drilling methods, hammer weight and fall, name of personnel logging the boring, and weather information. All information should be provided on the first sheet of each boring log.

4.3 BORING LOCATIONS AND ELEVATIONS

The boring location (coordinates and/or station and offset) and ground surface elevation (with datum) must be recorded on each boring log. Procedures discussed in Section 2.5.3 should be used for determining the location and elevation for each boring site.

4.4 STRATIGRAPHY IDENTIFICATION

The subsurface conditions observed in the soil samples and drill cuttings or perceived through the performance of the drill rig (for example, rig chatter in gravel, or sampler rebounding on a cobble during driving) should be described in the wide central column on the log labeled "Material Description", or in the remarks column, if available. The driller's comments are valuable and should be considered as the boring log is prepared. In addition to the description of individual samples, the boring log should also describe various strata. The record should include a description of each soil layer, with solid horizontal lines drawn to separate adjacent layers. It is important that a detailed description of subsurface conditions be provided on the field logs at the time of drilling. Completing descriptions in the laboratory is not an acceptable practice. Stratification lines should be drawn where two or more items in the description change, i.e., change from firm to stiff and low to high plasticity. Minor variations can be described using the term 'becoming'. A stratification line should be drawn where the geological origin of the material changes and the origin (if determined) should be designated in the material description or remarks column of the log. Dashed lines should be avoided.

The stratigraphy observations should include identification of existing fill, topsoil, and pavement sections. Careful observation and special sampling intervals may be needed to identify the presence and thickness of these strata. The presence of these materials can have a significant impact on the conclusions and recommendations of the geotechnical studies.

Individual strata should be marked midway between samples unless the boundary is encountered in a sample or special measurements are available to better define the position of the boundary.

4.5 SAMPLE INFORMATION

Information regarding the sampler types, date and time of sampling, sample type, sample depth, and recovery should be shown on each log form using notations and a graphical system or an abbreviation system as designated in Figures 4-4 and 4-5. Each sample attempt should be given a sequential number marked in the sample number column. If the sampler is driven, the driving resistance should be recorded at the specified intervals and marked in the sampling resistance column. The percent recovery should be designated as the length of the recovered sample referenced to the length of the sample attempt (example 550/610 mm).

4.6 SOIL DESCRIPTION / SOIL CLASSIFICATION

Soil description/identification is the systematic, precise, and complete naming of individual soils in both written and spoken forms (AASHTO M 145, ASTM D-2488), while soil classification is the grouping of the soil into a category; e.g., group name and symbol (AASHTO M 145, ASTM D-2487).

The soil's description should include as a minimum:

- Apparent consistency (for fine-grained soils) or density (for coarse-grained soils) adjective
- Water content condition adjective (e.g., moist)
- Color description
- Minor soil type name with "y" added if component is less than 30 percent
- Descriptive adjective for main soil type
- Particle-size distribution adjective for gravel and sand
- Plasticity adjective and soil texture (silty or clayey) for inorganic and organic silts or clays
- Main soil type name (all capital letters)
- Descriptive adjective such as "some" or "trace" for minor soil type if less than 30 percent
- Descriptive term for minor type(s) of soil
- Inclusions (e.g., concretions)
- The Unified Soil Classification System (USCS) Group Name and Symbol (in parenthesis) appropriate for the soil type in accordance with AASHTO M 145, ASTM D 3282, or ASTM D 2487. For classification of highway subgrade material, the AASHTO classification system is used.
- Geological name (e.g., Pleistocene), if known, (in parenthesis or in notes column)

The various elements of the soil description should generally be stated in the order given above. For example:

Fine-grained soils: Soft, wet, gray, high plasticity CLAY, trace f. Sand; Fat CLAY (CH); (Alluvium)

Coarse-grained soils: Dense, moist, brown, silty m-f SAND, trace f. Gravel to c. Sand; Silty SAND (SM); (Alluvium)

Some local practices omit the USCS group symbol (e.g., CL, ML, etc.) but include the group symbol at the end of the description. When changes occur within the same soil layer, such as change in apparent density, the log should indicate a description of the change, such as "same, except very dense".

4.6.1 Consistency and Apparent Density

Empirical values for the consistency of fine-grained soils and the apparent density of silts and coarse-grained soils have been developed for the blow count (*N*-value) resistance from Standard Penetration Test (AASHTO T-206, ASTM D 1586). The consistency of fine-grained soil is based on the uncorrected blow count while the apparent density of coarse-grained soil is based on the corrected blow count. Guidelines in Tables 4-1 and 4-2 are suggested to estimate the consistency or apparent density of soils.

The apparent density or consistency of the soil formation can vary from these empirical correlations for a variety of reasons. Judgment remains an important part of the visual identification process. Mechanical tools such as the pocket (hand) penetrometer, and field index tests (smear test, dried strength test, thread test, etc.) are suggested as aids in estimating the consistency of fine grained soils.

In some cases the sampler may pass from one layer into another of markedly different properties; for example, from a dense sand into a soft clay. In attempting to identify apparent density, an assessment should be made as to what part of the blow count corresponds to each layer; realizing that the sampler begins to reflect the presence of the lower layer before it reaches it.

Geotechnical evaluations of the relative density of coarse-grained soils require the blow count to be corrected to allow for changes in the overburden pressure. The criteria presented in U.S. Bureau of Reclamation Earth Manual (1960) should be used to calculate the relative density of coarse-grained soils.

4.6.2 Water Content (Moisture)

The amount of water present in the soil sample or its water content adjective should be described as dry, moist, or wet as indicated in Table 4-3.

4.6.3 Color

The color should be described when the sample is first retrieved at the soil's as-sampled water content (the color will change with water content). Primary colors should be used (brown, gray, black, green, white, yellow, red). Soils with different shades or tints of basic colors are described by using two basic colors; e.g., gray-green. Note that some agencies may require Munsell color and carry no inferences of texture designations. When the soil is marked with spots of color, the term "mottled" can be applied. Soils with a homogeneous texture but having color patterns which change and are not considered mottled can be described as "streaked".

TABLE 4-1
EVALUATION OF THE APPARENT DENSITY OF COARSE-GRAINED SOILS

N-value	Apparent Density	Behavior of 13 mm Diameter Probe Rod	Relative Density, %
0 - 4	Very loose		
>4 - 10	Loose	Easily penetrated when pushed by hand	0 - 40
>10 - 30	Medium dense	Easily penetrated when driven with 2 kg. hammer	40 - 70
>30 - 50	Dense	300 mm penetration when driven with 2 kg. hammer	70 - 85
>50	Very Dense	Only a few centimeters penetration when driven with 2 kg. hammer	85 - 100

TABLE 4-2
EVALUATION OF THE CONSISTENCY OF FINE-GRAINED SOILS

N-value	Consistency	Unconfined Compressive Strength, q_u, kPa	Results Of Manual Manipulation
<2	Very soft	<25	Specimen (height = twice the diameter) sags under its own weight; extrudes between fingers when squeezed.
2 - 4	Soft	25 - 50	Specimen can be pinched in two between the thumb and forefinger; remolded by light finger pressure.
4 - 8	Medium stiff	50 - 100	Can be imprinted easily with fingers; remolded by strong finger pressure.
8 - 15	Stiff	100 - 200	Can be imprinted with considerable pressure from fingers or indented by thumbnail.
15 - 30	Very stiff	200 - 400	Can barely be imprinted by pressure from fingers or indented by thumbnail.
>30	Hard	>400	Cannot be imprinted by fingers or difficult to indent by thumbnail.

TABLE 4-3
ADJECTIVES TO DESCRIBE WATER CONTENT OF SOILS

Description	Conditions
Dry	No sign of water and soil dry to touch
Moist	Signs of water and soil is relatively dry to touch
Wet	Signs of water and soil definitely wet to touch; granular soil exhibits some free water when densified

4.6.4 Type of Soil

The constituent parts of a given soil type are defined on the basis of texture in accordance with particle-size designators separating the soil into coarse-grained, fine-grained, and highly organic designations. Soil with more than 50 percent of the particles larger than the (U.S. Standard) No. 200 sieve (0.074 mm) is designated coarse-grained. Soil (inorganic and organic) with 50 percent or more of the particles finer than the No. 200 sieve is designated fine-grained. Soil primarily consisting of less than 50 percent by volume of organic matter, dark in color, and with an organic odor is designated as organic soil. Soil with organic content more than 50 percent is designated as peat. The soil type designations follow ASTM D 2487; i.e., gravel, sand, clay, silt, organic clay, organic silt, and peat.

Coarse-Grained Soils (Gravel and Sand)

Coarse-grained soils consist of gravel, sand, and fine-grained soil, whether separately or in combination, and in which more than 50 percent of the soil is retained on the No. 200 sieve. The gravel and sand components are defined on the basis of particle size as indicated in Table 4-4.

The particle-size distribution is identified as well graded or poorly graded. Well graded coarse-grained soil contains a good representation of all particle sizes from largest to smallest, with ≤ 12 percent fines. Poorly graded coarse-grained soil is uniformly graded with most particles about the same size or lacking one or more intermediate sizes, with ≤ 12 percent fines.

The flow chart to determine the group symbol and group name for coarse-grained soils is given in Figure 4-6. This figure is identical to that of Figure 2 in ASTM D 2487 except for the following recommendations:

1. Capitalize primary soil type; i.e., GRAVEL.
2. Add group symbols and names to identify that the fines are organic. Some examples are presented in Table 4-5.

Gravels and sands may be described by adding particle-size distribution adjectives in front of the soil type following the criteria given in Table 4-6.

Based on correlation with laboratory tests, the following simple field identification tests can be used as an aid in identifying granular soils.

Feel and Smear Tests: A pinch of soil is handled lightly between the thumb and fingers to obtain an impression of the grittiness or of the softness of the constituent particles. Thereafter, a pinch of soil is smeared with considerable pressure between the thumb and forefinger to determine the degrees of roughness and grittiness, or the softness and smoothness of the soil. Following guidelines may be used:

- Coarse- to medium-grained sand typically exhibits a very harsh and gritty feel and smear.
- Coarse- to fine-grained sand has a less harsh feel, but exhibits a very gritty smear.
- Medium- to fine-grained sand exhibits a less gritty feel and smear which becomes softer and less gritty with an increase in the fine sand fraction.