NATIONAL ENGINEERING HANDBOOK

SECTION 8

ENGINEERING GEOLOGY

CHAPTER 2. EXPLORATION METHODS AND EQUIPMENT

Introduction

This chapter outlines briefly the various methods of subsurface exploration applicable to SCS work and describes types of cutting and sampling tools and other equipment needed to conduct geologic investigations of dam sites.

Exposed Profiles

Natural Exposures

A complete investigation of formations in natural exposures at the surface is necessary to provide a basis for subsurface investigations and to eliminate unnecessary drilling. Natural exposures, when described in detail, serve the same purpose as other logs in establishing stratigraphy and other geologic conditions. A fresh surface is required for the preparation of adequate descriptions. An ordinary hand shovel or geologist's pick may be required for preparing the surface of a natural exposure.

Trenching and Test Pitting

General - Trenching and test pitting are simple methods of shallow exploration of easily excavated rock or soil materials which permit visual inspection of strata. This is of great value in logging profiles and selecting samples. If bedrock is anticipated at a shallow depth, trenches and test pits should be located on the centerline of the structure and dug parallel with it.

If bedrock is not at shallow depths, deep trenches or test pits should be offset from the centerline to avoid damaging the foundation of the structure. Shallow trenches or test pits may be dug adjacent to the centerline for correlation purposes.

In cases where pits or trenches penetrate or pass through materials which will constitute the foundation, it is a requisite that backfilling be performed in such a manner as to obtain soil densities (compaction) at least equal to the density of the original, in-place material. It is recognized that certain limitations exist in the use of trenching and test-pit excavating equipment for compacting fill material. However, every practical effort should be made to re-establish the inplace densities of foundation materials.

Trenches - Trenches imply long, narrow excavations. They are advantageous for studying the various formations on steep slopes and in exposed faces. Trenches made by power equipment, such as backhoes, draglines, and bulldozers, may require hand trimming of the sides and bottom to reach relatively undisturbed material.

The method is of particular value in delineating the rock surface beneath the principal spillway and in abutments and in exploring emergency spillway materials. In materials containing many cobbles or boulders, where drilling is difficult, trenching may be the most feasible method of investigation. On the center-line of the dam, trenches may yield valuable information on rock excavation and core trench depth, especially where thin-bedded or flaggy rocks are found near the surface.

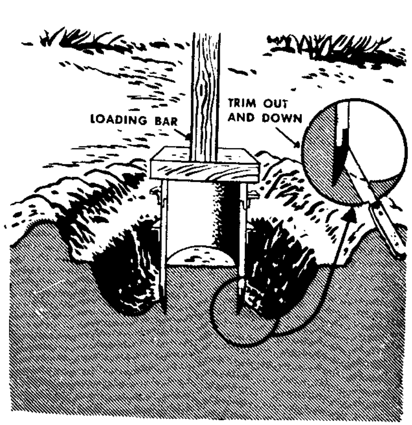
Test pits - Test pits are rectangular or circular excavations large enough to admit a man with sampling equipment. They may be excavated by hand or by the use of power equipment such as a clamshell or orange-peel bucket. Power equipment should be used only for rough excavation and with extreme caution when approaching the depths at which undisturbed samples are to be taken. Cribbing is required in unstable ground and for deep pits.

The advantages of test pitting are about the same as for trenching, but have the added advantage of being adaptable to greater depths at less cost. Disadvantages include time loss and cost where cribbing is necessary. With adequate dewatering equipment, they can be extended below the water table and with cribbing they can penetrate unstable materials.

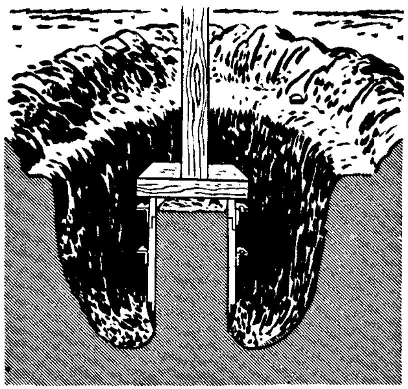
<u>Procedures for Obtaining Undisturbed Samples from Exposed Profiles</u>
Undisturbed hand-cut samples can be obtained above the water table from nearly all types of materials with less disturbance than by other means.

Undisturbed samples may be obtained as box, cylinder, or chunk samples. Box samples are hand-cut and trimmed to cubical dimensions and sealed in individual boxes for handling and shipping. They should have a minimum dimension of six inches. Cylinder samples from four to eight inches in diameter and six to twelve inches long can also be hand-cut by sliding a cylinder over a column of soil which is trimmed to approximate size in advance of the cylinder. Cylinder samples may also be obtained by jacking or otherwise pushing thin-wall drive samples into exposed surfaces using a continuous steady pressure. Chunk samples are of random size and shape and are broken away from the soil mass with or without trimming. They are difficult to package and ship but are simple to obtain.

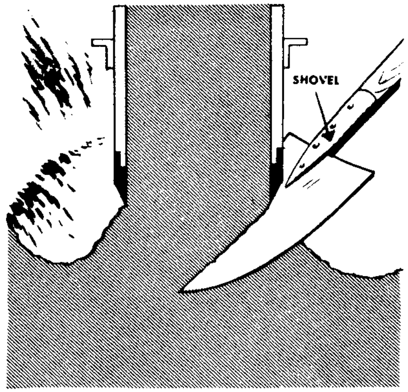
Figures 2-1, 2-2, and 2-3 demonstrate the methods of obtaining and packaging hand-cut samples.



Press mold down over soil firmly, using loading bar if necessary. Carefully trim soil away from sampling collar with knife. Cut downward and outward to avoid cutting into sample. The actual cutting to size is done with sampling collar.



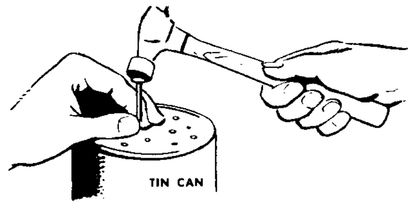
Excavate trench deeper and repeat process until soil penetrates well into extension collar.



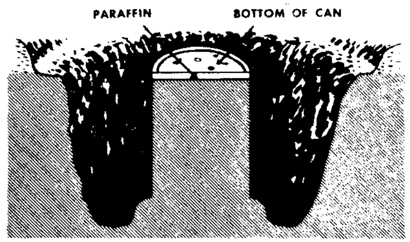
Cut off sample at bottom of mold with shovel, butcher knife, or wire saw and remove from hole.

Remove upper collar and trim top surface of sample; then turn mold upside down, remove sampling collar, and trim bottom. The top and bottom surfaces must be trimmed level with ends of mold. Protect ends with wood discs and tape around edges.

NOTE: If stones interfere, pick them out carefully and backfill with soil. Record this fact in log of sample whenever this is done.



1. Punch holes in bottom of can.



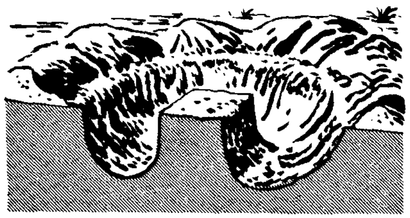
2. Excavate around can in the same way as for compaction mold and press down until soil penetrates to bottom of can.

3. Pour paraffin in holes and seal bottom of can. Cut off sample with butcher knife and remove from hole.

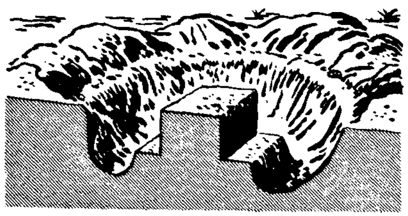
4. Cut surface about ½-inch below top of can and fill with paraffin.

Figure 2-1 Methods of Obtaining Cylinder Samples

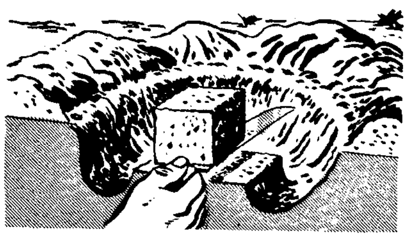
To obtain a chunk sample from a subgrade or other level surface such as the bottom of a test pit:



1. Smooth ground surface and mark outline of chunk.
2. Excavate trench around chunk.



3. Deepen excavation and trim sides of chunk with butcher knife.



4. Cut off chunk with butcher knife, trowel, or hacksaw blade and carefully remove from hole.

To obtain a chunk sample from the vertical face of a test pit or shovel cut:

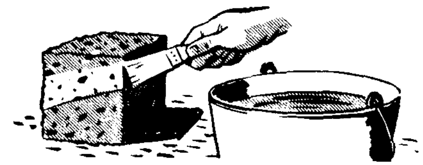
1. Carefully smooth face surface and mark outline of chunk.

2. Excavate around and in back of chunk. Shape chunk roughly with butcher knife.

3. Cut off chunk and carefully remove from hole.

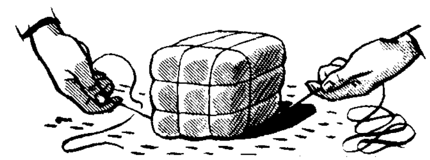
To seal chunk after removing it from hole:

1. Trim and shape rough edges with butcher knife.



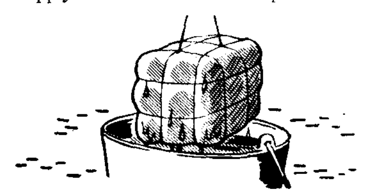
2. Apply three coats of paraffin with paint brush. Allow each coat to cool and become firm before applying next coat.

NOTE: This gives adequate protection for strong samples that are to be used within a few days. Samples that are weak or may not be used soon require additional protection.



3. Wrap with cheesecloth or other soft cloth. If cloth is not available, reinforce with several loops of friction tape or twine.

4. Apply three more coats of paraffin.

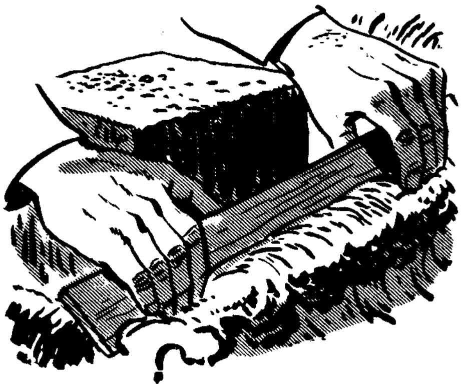


NOTE: A better method is to dip entire sample in melted paraffin after first brush coat is applied. This requires a large container and more paraffin, but gives a more uniform coating. By repeated dipping, paraffin can be built up to a minimum 1/8-inch thickness.

Figure 2-2. Chunk Samples

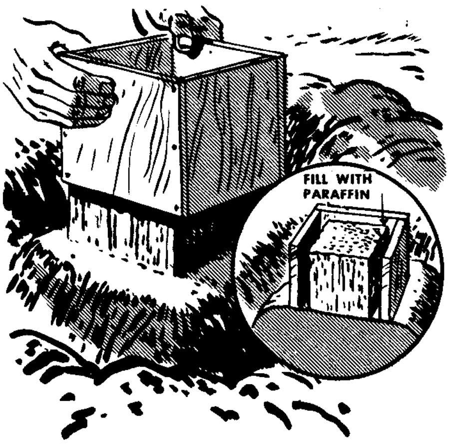
Box Samples

Box samples are sometimes used for large undisturbed samples requiring extensive investigation. They can be firmly packed for shipment or storage, but require considerable paraffin.

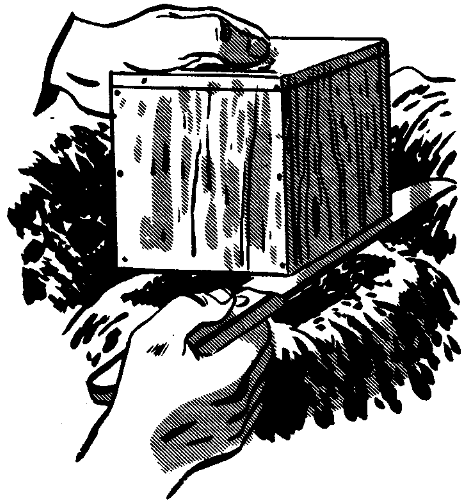


To obtain a box sample:

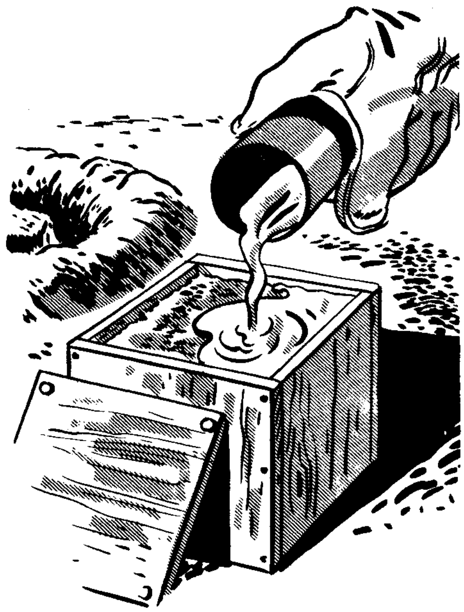
1. Excavate as for a chunk sample, then trim sample to size slightly smaller than box.



2. Remove top and bottom from box and place over sample.
3. Fill sides with paraffin, then pour paraffin over top of sample and replace bottom.



4. Cut off sample, remove box containing sample from hole, and turn right side up.



5. Trim surface of sample and seal with melted paraffin, then replace lid.

Figure 2-3. Box Samples

Bore Holes

General
Bore holes represent a common method of exploration in making sub-surface investigations. Various types of drilling equipment and tools are available for advancing bore holes. Bore holes are advanced for (1) general investigation during preliminary examination, (2) obtaining representative disturbed samples, (3) for advancing and cleaning holes to specific horizons for logging, sampling, or conducting tests, (4) for advancing holes to bedrock to delineate rock surfaces, and (5) for installing piezometers and relief wells, Only the more common methods of boring for SCS work are described in this section.

Hand-auger Borings
Hand augers are useful for advancing holes to shallow depths for preliminary examination of sites. They may be used to depths up to 20 feet. Beyond that depth they become cumbersome to handle and boring is slow. Usually a bucket-type hand auger is found to be most useful because it provides samples for inspection without the excessive mixing of materials which occurs when a helical or wormtype bit is used.

Several kinds of motorized hand augers (post-hole augers) are available on the market. Although a shallow hole can be advanced rapidly with this type of equipment, the limitations in use are similar to those of hand augers.

Power-auger Boring
Power augers mounted on trucks or jeeps are used for dry boring in unconsolidated materials. Bore holes are advanced by rotating a cutting bit into the materials. A wide variety of materials may be bored with power augers. They are not suitable for use in materials containing cobbles or gravel, hard or cemented soils, or saturated cohesionless soils. Unstable materials require casing particularly below the water table.

In power-auger boring, materials are brought to the surface by lifting the bit and removing materials contained therein, or, by use of a continuous flight or helical auger which spirals the material to the surface by mechanical means. Raising the bit for cleaning each time results in slow advancement of holes. However, it facilitates inspection of materials from strata of known depth. The continuous flight auger provides a more rapid method of advancing holes. The material brought to the surface is badly mixed by the action of the flight auger and correlation with depth is always questionable so that definite identification and location of changes of strata is not possible.

The use of power augers usually leaves the hole clean and dry above the water table and the materials in the bottom of the hole relatively undisturbed.

Percussion or Churn Drilling
Percussion or churn drilling is an inexpensive method of advancing bore holes through hard consolidated soils, rock, coarse gravel deposits, or formations containing boulders. It is often used in conjunction with auger boring.

The hole is drilled by the impact and cutting action of a heavy, chisel-edged drilling tool that is alternately raised and dropped by means of a cable attached to a walking arm, "jerkline," crank, or other means of raising and dropping the cable and tools.

A small amount of water in the bore hole permits the loosened rock and soil to be mixed into a slurry as the hole is advanced. When the carrying capacity of the slurry is reached, the drilling bit is removed from the hole and the slurry removed by means of a bailer or sand pump, usually operated by a separate winch and light cable or "sand line." When drilling clay materials, the addition of sand will augment the cutting action of the bit. Also, when drilling in cohesionless materials, the addition of clay will increase the carrying capacity of the slurry.

Except in extremely stable materials, churn-drill holes usually require casing. It is desirable that the hole be advanced ahead of the casing, but this is often impossible in soft or sandy soils. Because of mixing of materials, the materials removed from the hole are non-representative and inadequate for delineation of particular strata.

Wash Borings
A wash boring is a means of rapidly advancing a hole by a striking or rotating, cutting or chopping tool and by jetting with water which is pumped through the hollow drill rod and bit. The method usually requires use of casing. Cuttings are removed from the hole by the water circulating upward between drill rod and casing. The cutting tool is alternately raised and dropped by tightening and slacking of a line wrapped around a cathead. A tiller attached to the drill rod permits rotating the rod and cutting tool. The material brought to the surface in the circulating water is non-representative of materials in place. Consequently, positive identification of particular strata is not possible when holes are advanced by the wash-boring method.

Displacement Borings
This method consists of forcing a tube into soil materials and withdrawing material which is retained inside the tube. Tubes may be driven by use of a drive hammer or pushed using a jack or hydraulic cylinders against the weight of the rig. Displacement

boring can be made in clays. silts and relatively stable materials free from gravel, cobbles, and boulders. The sampler, when withdrawn, acts as a piston in the hole causing more excessive caving than other methods of boring. Although highly recommended for logging purposes, continuous drive boring represents a slow method of advancing holes when needed for purposes other than loggine. Even minor changes in soil materials can readily be detected by extruding samples from the tubes. However, when used for logging purposes, the hole should be advanced by other means, such as auger boring, and tubes smaller than the hole diameter should be used in order to provide wall clearance. Displacement boring for advancing holes is generally impractical for diameters larger than three inches.

Rotary Drilling

In rotary drilling, the bore hole is advanced by rapid mechanical rotation of the drilling bit which cuts, chips, and grinds the material at the bottom of the hole into small particles. The cuttings are normally removed by pumping water or drilling fluid, from a sump, down through the drill rods and bit and up through the hole, from which it flows into a settling pit and back to the sump. Compressed air is available on many newer rigs to remove the cuttings from the hole. However, this is not very satisfactory in wet formations which are frequently encountered in dam site investigations.

A reverse water circulation is employed on rigs used to drill large-diameter holes such as water wells. In this case the drilling fluid passes down through the hole and up through the drill rods. The higher upward velocity of the fluid through the drill rods facilitates removal of cuttings from large holes.

Holes can be advanced in a wide variety of materials, including sound rock, by rotary-drilling methods. Rotary drilling may be the only practical method of advancing holes and obtaining undisturbed core samples from certain types of soil and rock materials. Rotary-drilling equipment is versatile. Any of the foregoing methods of advancing holes can be used with rotary-drilling equipment.

Geophysical Methods

Geophysical methods may be used to supplement test holes for geologic exploration. It is desirable to have a limited number of test holes for interpretation of results obtained by geophysical procedures. Geophysical methods are rapid and economical and may reduce the number of test holes that are required at a particular site to establish geologic continuity. With test hole control, geophysical methods may be helpful in delineating the bedrock profile and determining the continuity of strata between borings for certain types of geologic conditions.

Seismic

The seismic refraction method is based on the variable rate of transmission of seismic or shock waves through materials of varying densities composing the earth's crust. The nature of material is inferred from the rate of transmission of sound. Typical rates of transmission for different types of materials are shown in Figure 2-4.

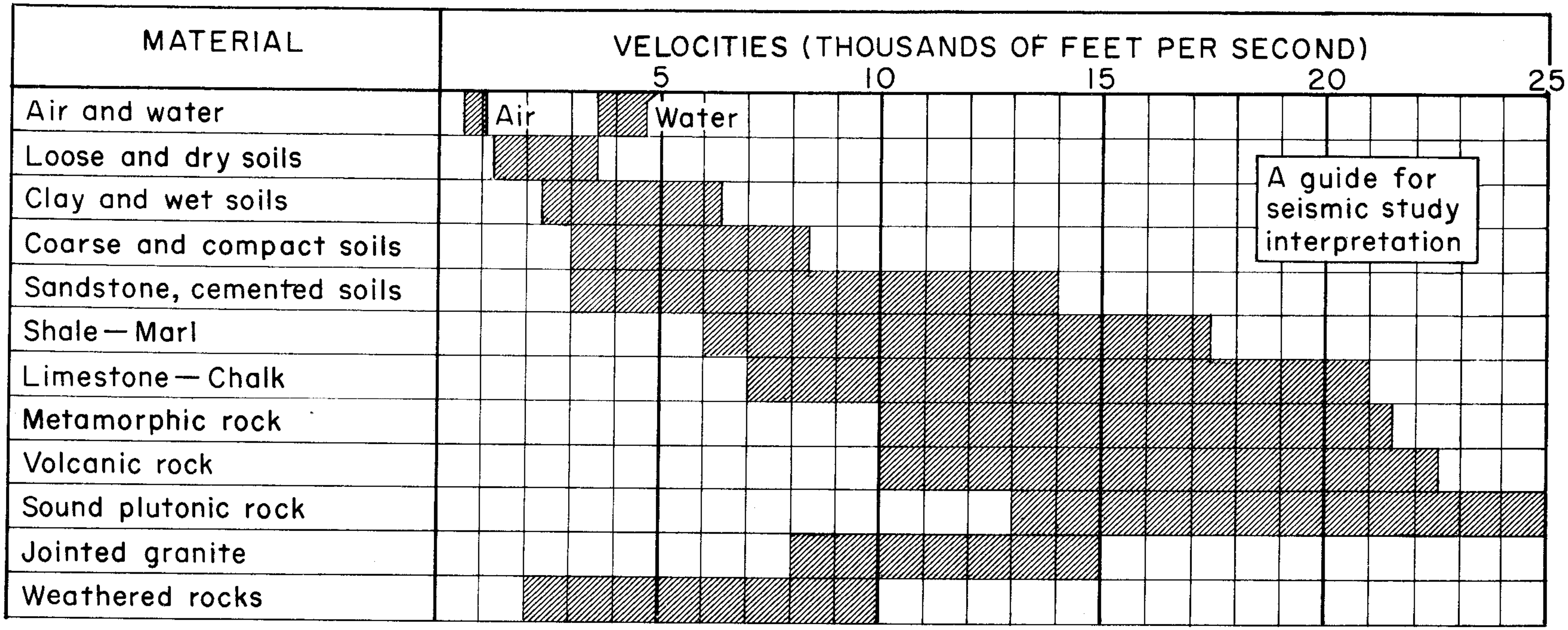


Figure 2-4. Velocities of Longitudinal or Compression Waves.

Hvorslev, M.J., ASCE, Nov. 1949

Several types of operating procedures have been developed. In one method, small explosive charges are set off in shallow holes. The seismic wave so generated is picked up and its time of arrival is recorded at several surface detecting points. The travel time of the wave to these recording points is measured and the wave velocity of different strata may be calculated. From these data the depths and probable character of various beds or layers can be inferred. See Figure 2-5 for schematic drawing.

Light-weight portable refraction seismographs have been developed which accurately measure the time interval for travel of a sound wave from a source to the instrument. In this method the shock wave is created by a sledge hammer blow on the ground and is picked up by a geophone. These portable units may be equipped with one or more geophones. The mechanical energy of the wave is transformed by the geophone into an electrical signal which in turn is fed into the receiver. The time interval of the seismic wave is read directly on the instrument by means of binary counters or is recorded on film or paper.

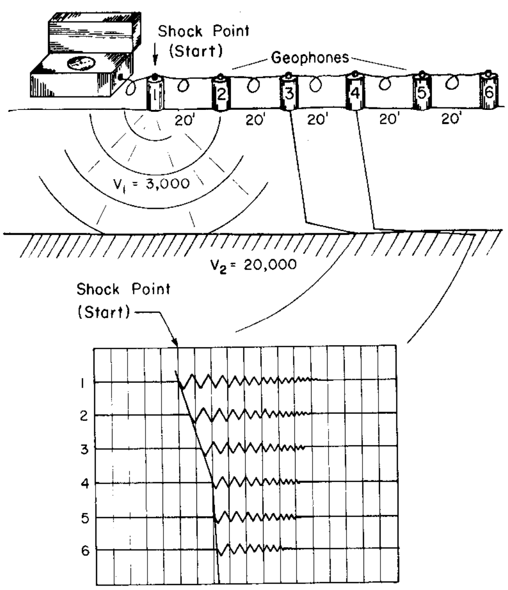
The velocity of the wave is then computed from the registered time and the distance of the hammer from the instrument. Changes in the physical characteristics of underlying materials are indicated by the changes in velocities (distance/ time) recorded by the instrument.

The instrument, when the shock wave is created by a hammer blow, is limited to depths of about 50 feet and to rather simple problems of geology. For example: (1) a single discontinuity between two formations, (2) dipping discontinuity, and (3) two horizontal discontinuities, providing each formation becomes progressively denser with depth. Because the velocity of sound in water is about 5,000 fps., groundwater tables can be delineated in formations having seismic velocities less than that of water. The equipment is relatively inexpensive compared to seismographs used for oil and mineral exploration work. Although used only to a limited extent in foundation exploration, it appears to have possibilities for preliminary studies and for reducing the number of test holes needed to extrapolate continuity.

<u>Electrical Resistivity</u>

The resistivity, or electrical resistance, of earth materials can be determined readily by causing an electrical current to flow through the materials being tested. Usually, four electrodes are set in the ground in a line and at an equal distance apart. A set of batteries and a milliammeter are connected in series with the outer pair of electrodes. These are the two current electrodes. A potentiometer for measuring voltage is connected with the inner pair of electrodes. They are the potential electrodes. In many types of instruments a device, such as a commutator, is incorporated in the circuit

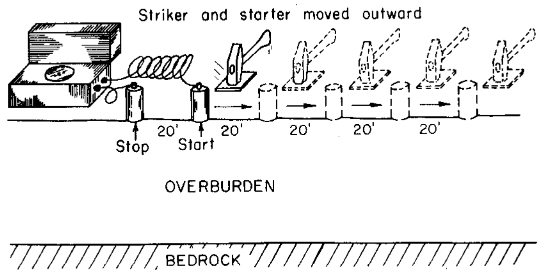
MULTI-TRACE RECORDING REFRACTION SEISMOGRAPH



SEISMOGRAM

Time lines 0.01 sec. apart

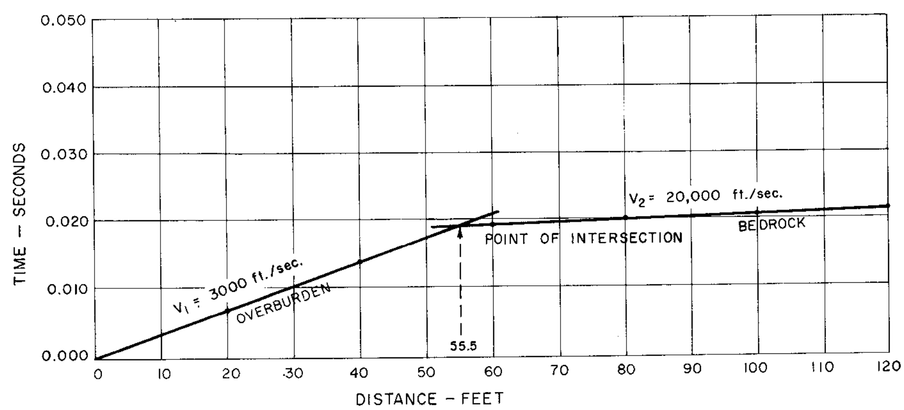
PORTABLE REFRACTION VISUAL TIMER



DISTANCE (FEET)	TIME (MILLISECONDS)
20	5, 6, 7, 6, 7, (7)
40	13, 12, 14, 13, (13)
60	19, 18, 19, (19)
80	20, 21, 20, (20)
100	21, 21, (21)
120	22, 23, 46, 22, (22)

TIME RECORD

Visual readings from timer



V = Shock wave velocity = $\frac{D}{T}$ = ft./sec.

D = Distance to point of intersection (feet).

T = Time to point of intersection (seconds).

H = Overburden thickness = $\frac{D}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$

V_1 = Overburden velocity

V_2 = Bedrock velocity

Figure 2-5. Seismic Refraction Methods

for the purpose of reversing the polarity of the current electrodes (Figure 2-6). This procedure permits the registering of several potential readings for comparison. By measuring the current and the potential drop between the two inner potential electrodes, the apparent resistivity of the soil to a depth approximately equal to the spacing interval of the electrodes can be computed. The resistivity unit may be designed so that the apparent resistivity is read directly on a potentiometer using the principle of a wheatstone bridge.

In sediments or loose rock the resistivity meter will show a marked drop in potential at the water table. However, in solid rock the greater resistance of the material will often mask the presence of the water table.

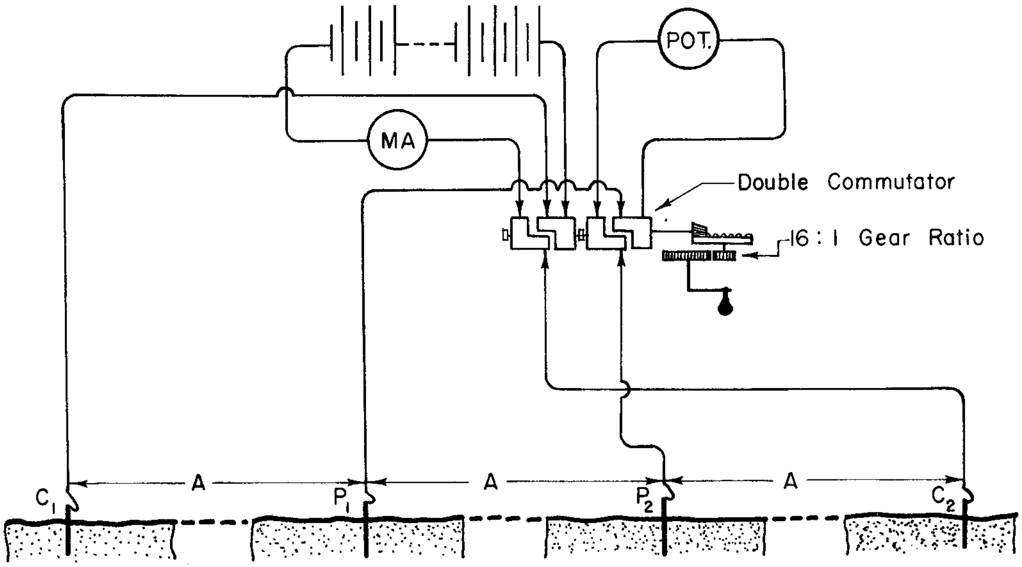
In "resistivity mapping" or "traverse profiling," the electrodes are moved from place to place without changing their spacing. The resistivity and any anomalies to a depth equal to the spacing of the electrodes can be determined for the various points.

In "resistivity sounding" or "depth profiling" the center point of the setup remains fixed while the spacing of the electrodes is changed. By plotting the apparent resistivity as a function of the electrode spacing, the subsurface conditions may be indicated. A break or change in curvature of the plotting will generally be noted when the electrode spacing equals the depth to a deposit with a resistivity differing from that of the overlying strata.

The electrical resistivity method and refraction seismographs have been used complementing each other with good results, particulary in delineating gravel lenses, bedrock and the groundwater table. However, salt water and saline soils have marked influence on conductivity. Excellent results have been obtained at swampy sites containing organic soils and saturated materials.

Field Penetration Test

This test provides a measure of the resistance of soil to penetration of the sampler. It also furnishes samples of the material penetrated for identification, classification, and other test purposes. This test is used to indicate relative in-place density of cohesionless and relative in-place consistency of cohesive foundation materials and for logging. Table 2-1 shows the relative density and consistence for various soils and blow counts.



Legend

MA – Milliammeter
POT. – Potentiometer
C_1, C_2 – Current Electrodes
P_1, P_2 – Potential Electrodes
A – Uniform spacing between electrodes

Figure 2-6. Diagram of Resistivity Apparatus

Table 2-1. Standard Penetration Resistance

Noncohesive Soils		Cohesive Soils	
Blows per Foot	Relative Density	Blows per Foot	Consistency
Less than 4	Very loose	Less than 2	Very soft
4-10	Loose	2-4	Soft
10-30	Medium	4-8	Medium
30-50	Dense	8-15	Stiff
Over 50	Very dense	15-30	Very stiff
		Over 30	Hard

Application

The standard penetration test is recommended for use in SCS work. It is most applicable to fine grained soils that are at or near saturation and to fairly clean, coarse grained sands and gravels at variable moisture contents. Materials below the water table may generally be considered to be saturated.

Equipment

Drilling equipment - Any equipment may be used that will provide a reasonably clean hole to insure that the test is performed on undisturbed material and that will drive and reclaim the sampler in accordance with the procedure outlined below. Where necessary, casing or hollow stem auger will be used to prevent caving. The hole will be at least 2¼ inches in diameter.

A, B, or N rod may be used, however A or B is preferred. If N rod is used, the minimum hole diameter should be 2 3/4 inches.

Bottom discharge fishtail bits, jetting through open tube or sand or water bailers will not be used to advance holes.

Split-tube sampler - The sampler shall have an outside diameter of 2 inches. It shall consist of (1) a hardened steel driving shoe at least 3 inches in length with an inside diameter at the cutting head of 1 3/8 inches. It shall be sharpened by tapering the last 3/4 inch to a cutting edge not greater than 1/16 inch thick. Dented, distorted, or broken shoes shall not be used; (2) the split tube shall have a minimum length of 16 inches and an inside diameter of 1 3/8 <u>or</u> 1 1/2 inches; (3) the coupling head shall have a minimum length of 6 inches. It will have four vents each with a minimum diameter of 1/2 inch <u>or</u> it shall contain a ball check valve and no side vents. (Figure 2-7)

Hammer - The drive hammer shall weigh 140 pounds and have a 30-inch stroke (free fall). Any type of hammer may be used as long as there is no interference with its free fall and its energy is not reduced by friction on the drill rod, guides, or other parts of the equipment.

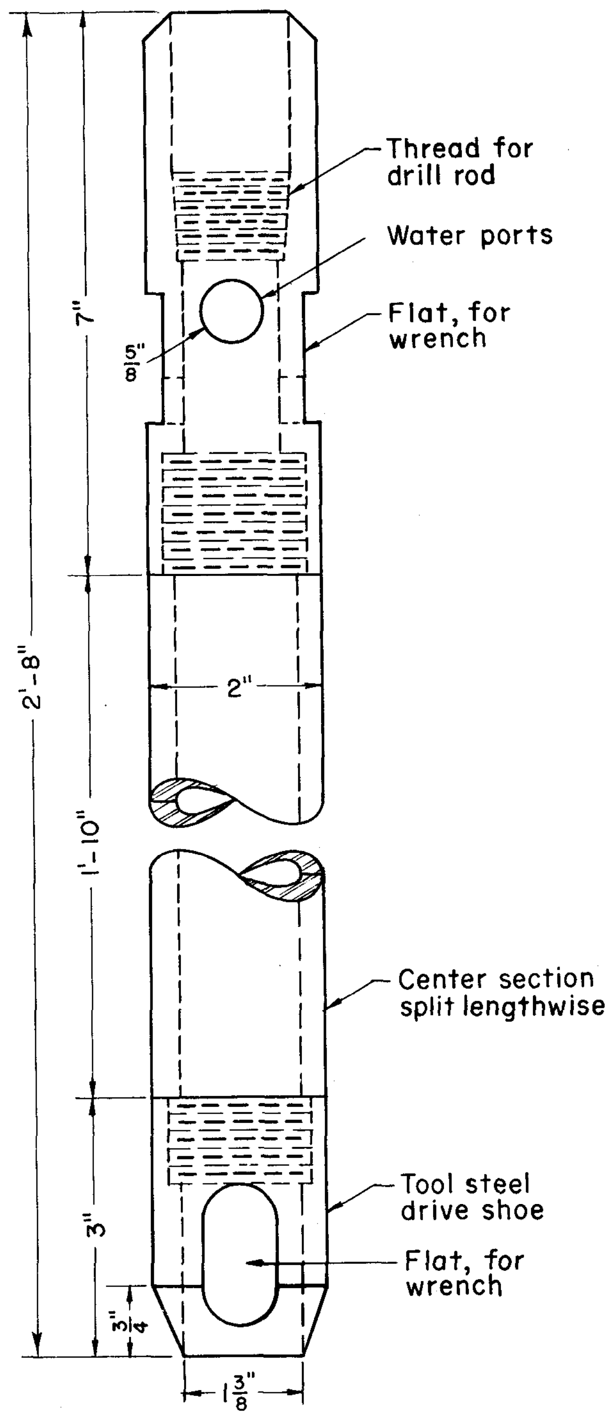


Figure 2-7. Split-Barrel Samples

Procedure

Cleaning hole - Clean the hole to the sampling elevation by use of equipment that will not disturb the material to be sampled. Do not use bottom discharge fishtail bits, jetting through an open tube, or sand water bailers. Take samples at each change in stratum and at intervals not greater than 5 feet. Never drive casing (or hollow stem auger) below the depth to which the hole is to be cleaned out.

The standard penetration test - Lower the split-tube sampler to the bottom of the cleaned hole. With the water level in the hole at the groundwater level or above, drive the sampler 6 inches with light blows so it will not be overdriven. Then drive the split-tube sampler 12 inches or to refusal, by dropping the 140-pound hammer 30 inches and record separately the number of blows required for each 6 inches of this 12-inch penetration test drive. Penetration of less than 1 foot in 100 blows is generally considered refusal. The blow count is the total number of blows required to drive this last 1 foot, or, with refusal, the number of inches penetrated by 100 blows.

The split-tube sampler is not to be used as a chopping bit. Where a boulder is encountered, it should be penetrated by other means (drilled or by chopping bit) or bypassed.

Remove the sampler from the hole and open it. Identify and classify the material or materials, record the percent recovery, place typical sample or samples in jars (without jamming or compressing), seal jars with wax and label. Label to show all data as to site location, location of hole and depth represented by sample, field classification, blow count, and percent recovery.

Vane Shear

The vane shear test provides a field method for determining the shearing resistance of a soil in place. See Figure 2-8. The vane, attached to the end of a rod, is forced into an undisturbed soil to be tested and rotated at a constant rate by means of a torque wrench or other calibrated torsion device attached to the rod. The moment or torque required to turn the vane is an indication of the shear strength of cohesive soils. Vane shear testing should be closely coordinated and carried out under the direction of the Unit Geologist.

Permeability Investigations

The coefficient of permeability is the rate of discharge of water under laminar flow condition through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions. There are two temperatures which are used as standard. These are 60°F and 20°C. Two

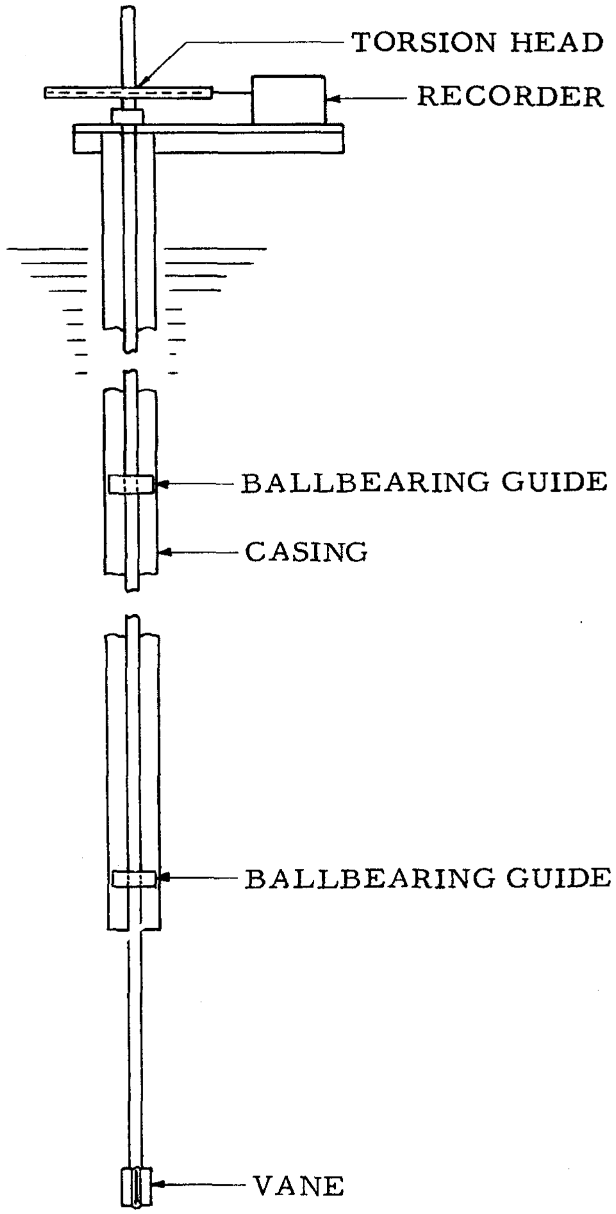


Figure 2-8. Idealized Vane Shear Apparatus

commonly used units for expressing the coefficient of permeability are: gallons per square foot per day under a hydraulic gradient of one foot per foot, and cubic feet per square foot per day under a hydraulic gradient of one foot per foot. This latter unit is commonly expressed as feet per day and treated as a velocity. This would be the discharge velocity under the conditions of unit head and standard temperature. Dividing this value by the porosity of the material will give the average velocity or dividing by the effective porosity of the material will give what Tolman[1/] terms the effective velocity or the actual velocity of the moving water.

Various field tests are used to determine water loss in rock formations. The test is carried out by means of sealing off portions of bore holes, introducing water under pressure, and measuring rate of water loss into the formation. Interpretation of results of pressure tests are illustrated in Figure 2-9. Pressure testing permits delineation of zones of leakage, for estimating grouting requirements or other treatment which may be needed to reduce water movement. Where pressure testing is required, bore holes should be tested in intervals of five feet or less.

Pressure-testing equipment - The apparatus commonly used for pressure testing foundations in rock consists of expansion plugs or packers set five feet apart, which may be expanded to seal off sections of a drill hole. See Figure 2-10. Water lines are so arranged that water may be admitted either below the bottom expansion joint or from a perforated pipe between the two expansion joints. The water lines are connected through a pressure relief valve, pressure gage, and water meter, to a pressure pump.

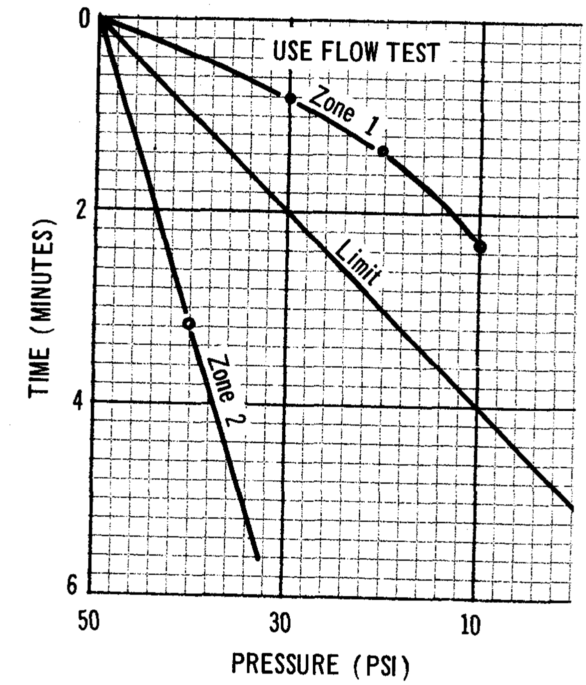
Water pumps having a minimum capacity of 50 gpm at discharge pressures of 100 psi are needed. Additional equipment includes accessory valves, gages, stopcocks, plugs, and tools necessary for maintaining uninterrupted tests.

Pressure-testing procedure - The following procedures apply in conduction a pressure test:

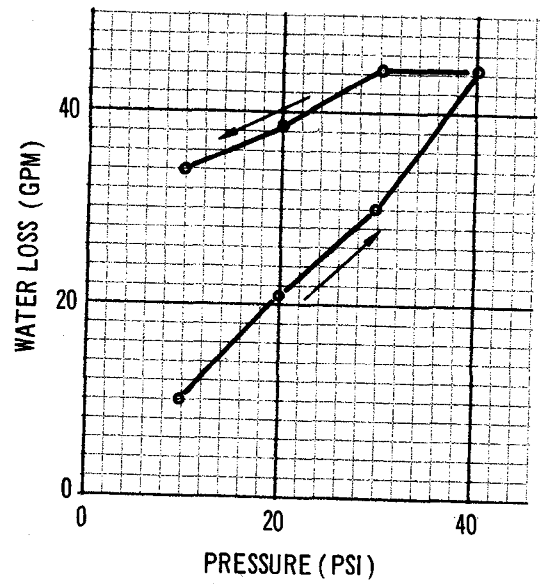
1. Lower the packer assembly in the bore hole to the predetermined depth of testing.

2. Expand the packers to seal off bore hole in section to be tested.

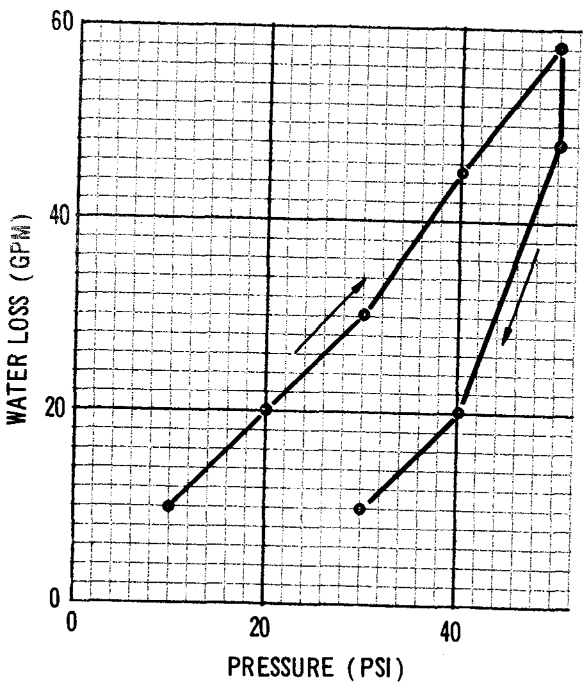
1/ Tolman, C. F., Ground Water, McGraw-Hill Book Co., Inc., New York and London, 1937, p. 216.



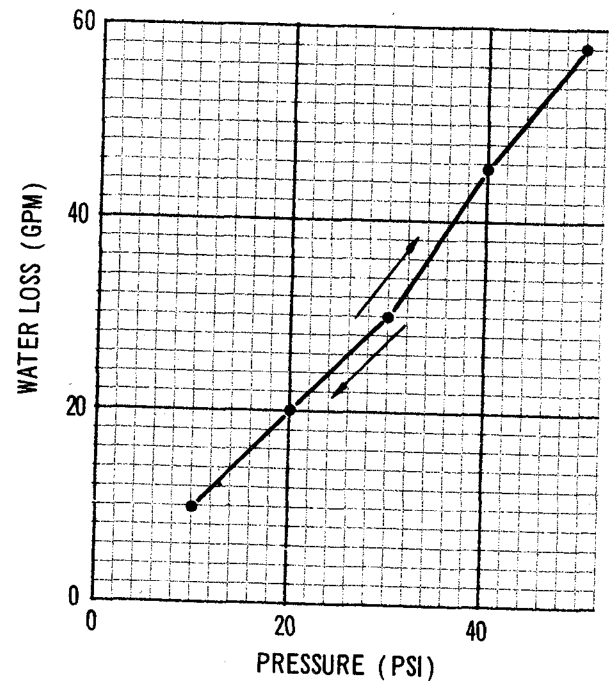
a. – Pressure holding test.



b. – Fissures opened by increased pressure (leakage problem).



c. – Self–sealing formation (no leakage problem).



d. – Stable condition (leakage problem).

Figure 2-9 Sample Plots of Pressure-Test Data

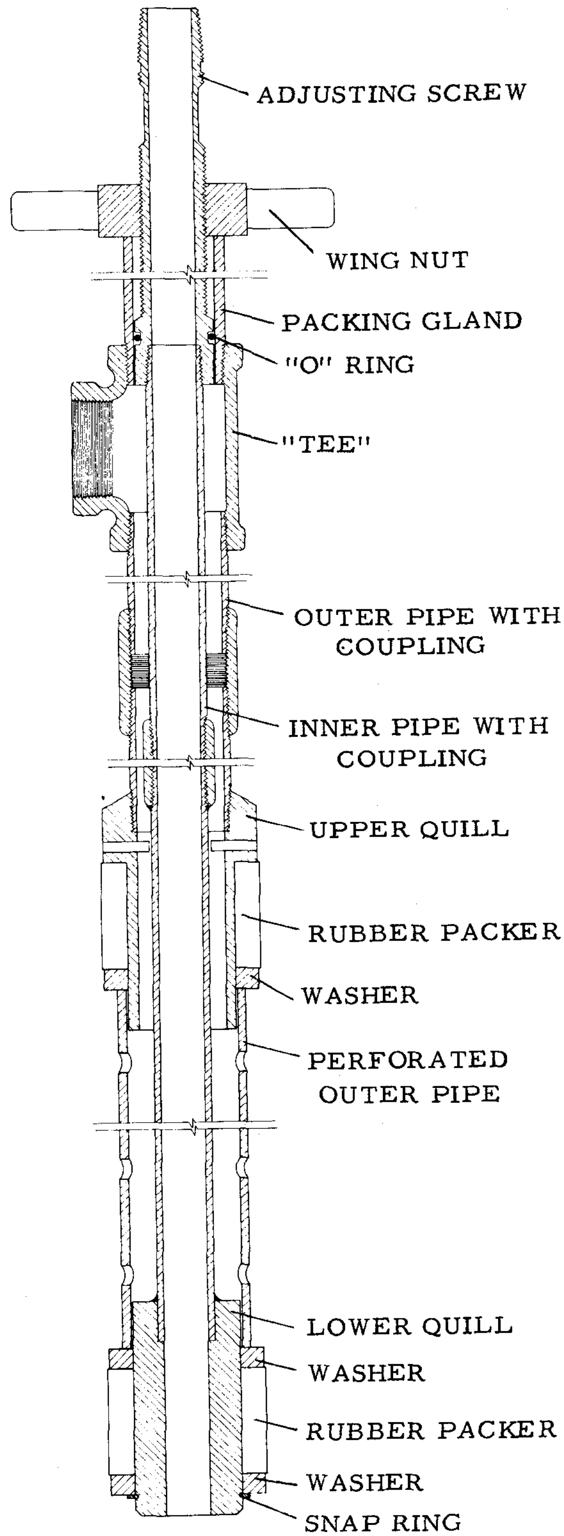


Figure 2-10. Pressure-testing Tool

3. Water under pressure is forced into the bore hole between packers by the pressure pump.

4. Adjust wa - pressure. Maximum water pressure at the upper packer for the holding test should not exceed one psi (pounds per square inch) per foot of hole depth.

5. When the initial test pressure is reached, close stopcocks and cut off pressure pump.

6. Record the pressure drop for various intervals of time to determine rate of drop.

7. If pressure drop exceeds 10 psi per minute, continue investigation with a flow test. A pressure drop of less than 10 psi per minute is evidence that no appreciable leakage occurs in the zone tested.

8. Where additional testing is indicated a packer type flow test may be used (see pumping-in tests below). In some types of material it may be desirable to determine rates of flow at several different pressures in ascending order from the lower to the higher pressure. The maximum pressure should not exceed 0.43 times the vertical distance in feet between the test elevation and the elevation of the emergency spillway. Then recheck these rates in descending order from the higher to the lower pressure. See Figure 2-9, b, c, and d.

9. Release water pressure between packers, contract expanders and move unit to next interval to be tested.

<u>Pumping-in Tests</u>

Each of the following tests applies to a certain set of conditions. If all of these conditions are not present, erroneous permeability coefficients will result.

Open-end tests - Open-end tests can be made in permeable formations either above or below the water table and with the use of gravity flow or pressure flow. The stratum being tested should have a thickness at least ten times the diameter of the test well. The test is based on the amount of water accepted at a given head by the formation through the bottom of a pipe or casing. Clear water must be used if valid results are to be obtained. It is also desirable that the temperature of the water being added be higher than the temperature of the groundwater to prevent the formation of air bubbles in the formation.

The casing should be sunk to the desired depth, leaving a foot or two protruding above ground. It is then carefully cleaned out just to the bottom of the casing. Drilling muds should not be used in making holes. Cleaning should proceed, using clear water, until clear water is returned to the surface. A standard cleanout auger (figure 2-24) or other tool with jet deflector or low-pressure jet should be used to avoid disturbance of the material below the casing. Below the water table the hole should be kept full of water at all times during cleaning to avoid forcing of the materials up into the casing by water pressure from below. This makes it necessary to determine the normal water level in the hole before cleaning.

The test is then begun by adding clear water into the hole, maintaining a constant water level in the casing, until a steady rate of intake is established. If pressure is applied, water should be pumped until rate of inflow and pressure remain steady. Above the water table a constant level and intake rate are rarely attained and a slight surging of the water level or pressure at constant inflow may occur. When the oscillations become regular for a few minutes the test can proceed. An anti-surge device consisting of a capped, air-filled, stand pipe may be placed in the supply line near the pressure gage. This will dampen the surges and make gage readings easier to take.

The length of the test should be measured with a stop watch. Normally, ten minutes should be long enough. The volume of water should be measured with a water meter or other method accurate within 1 or 2 percent. The rate of flow (Q) is then computed by dividing the volume by time. Q is usually recorded as gallons per minute.

Above the water table, head (h) is measured from the bottom of the hole to the elevation of the maintained water level. Below the water table it is measured from the groundwater level to the maintained level. If pressure is applied, head is measured from the bottom of the hole or the normal water level to the elevation of the gage, plus the applied pressure. If the gage reads in pounds per square inch, the pressure reading is multiplied by 2.31 to convert it to feet of head (1 psi = 2.31 ft.).

The size of casing is usually measured in inches. For this test, the radius (r) is the inside radius of the bottom of the casing.

Figure 2-11 illustrates the conditions and procedures discussed above.

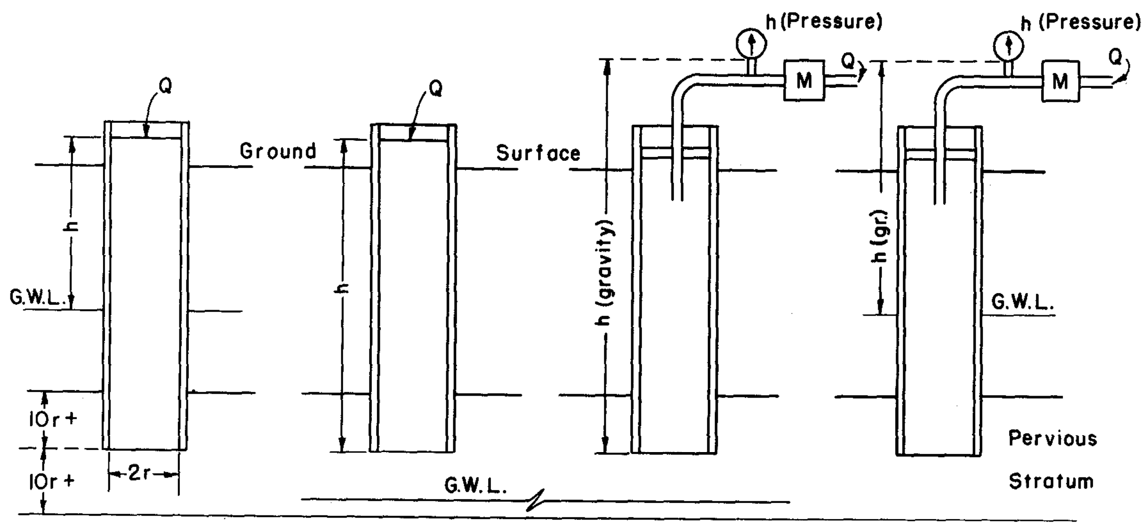


Figure 2-11 Open-end Permeability Test

Electric analog experiments conducted by the U.S.B.R. gave the following relationship between the above data and permeability:

$$k = \frac{Q}{5.5rh} \qquad (1)$$

where,

k = coefficient of permeability,

Q = constant rate of flow into the hole,

r = internal radius of the bottom of the casing,

h = differential head of water

Any consistent set of units can be used. As an example:

Data obtained in Field	Conversion to Consistent Set of Units
Q = 8.3 gallons per minute	= 1598 cubic feet per day
r = 1.5 inches	= 0.125 feet
h = 7.3 feet	= 7.3 feet

$$k = \frac{1598 \text{ ft}^3/\text{day}}{5.5 \times 0.125 \text{ ft} \times 7.3 \text{ ft}} = 318 \text{ ft}^3/\text{ft}^2/\text{day}$$

For convenience, the formula can be written:

$$k = \frac{420Q}{rh} \qquad (2)$$

where,

k is in cubic feet per square foot per day,

Q is in gallons per minute,

r is in inches, and

h is in feet.

Using the same data as in the above example:

$$k = \frac{420 \times 8.3}{1.5 \times 7.3} = \frac{3486}{10.95} = 318 \text{ ft}^3/\text{ft}^2/\text{day}$$

It should be remembered that this test is an approximation and should not be considered to give a precise value for permeability. It has the advantage of being a simple test which can be performed during normal drilling operations. It gives a good indication of relative permeabilities at various depths. The test should not be performed with the bottom of the hole less than a distance of 10r from either the top or bottom of the strata being tested.

Packer tests

Packer tests are commonly used for flow testing of bedrock formations after pressure holding tests have indicated a need for permeability determinations. In bedrock they are usually conducted with the use of packers, in which case different sections of a completed hole can be tested by moving the packers. They can be conducted in unconsolidated materials between the bottom of the hole and the end of the casing or packer set in the bottom of the casing. In unconsolidated material, it must be certain that there is no space between the outside of the casing and the wall of the hole. If the hole is too large, water will escape upward outside the casing, giving erroneous results. Driving the casing a few inches beyond the bottom of the bored hole and cleaning it out will alleviate this.

If unconsolidated materials cave into the hole, the test can be performed in the following way: (1) Drive the casing to the bottom of the hole and clean it out. (2) Accurately measure the depth of the hole. (3) Pour a measured volume (V) of coarse sand or gravel into the casing, filling it to a depth slightly in excess of the length to be tested. The permeability of the added gravel must exceed the permeability of the strata being tested by at least the ratio that the cylindrical and end area of the test section exceeds the end area of the casing. Otherwise, grossly erroneous rates will result. This determination must be based on judgment, obviously, because the permeability of the formation is unknown. If the length of the test section is kept short, using 3/8 to 1/4 inch gravel will usually be adequate for testing unsorted sands and gravels. (4) Withdraw the casing to the top of the test section. Be careful not to pull the casing above the top of the gravel inside the hole. (5) Accurately measure the depth to the gravel pack. Subtracting this depth from the depth of the bottom of the hole is the factor L (see Figure 2-12), needed in computations. (6) Determine the mean radius (r) of the test section by the following formula:

$$r\ (\text{ft}) = \sqrt{\frac{V\ (\text{cu ft})}{\pi L\ (\text{ft})}} \qquad (3)$$

where,

r = radius of test section, (ft.),

V = volume of gravel added to hole, (cu. ft.),

L = length of test section, (ft.).

After completion of the test, if desirable, the hole can be deepened and a test run at a lower elevation.

In tests between two packers, used in rock where the hole will stand, it is usually desirable to complete the hole to final depth, clean it out, fill it with water, and start testing at the desired intervals from the bottom upward. In this way the entire hole can be tested without removing the apparatus from the hole.

In tests below the watertable, head (h) is measured in the same way as for the open-end test. That is, the vertical distance, in feet, from the watertable to the pressure gage, plus 2.31 times the gage pressure reading. Above the watertable it is measured from the mid-point of the test section to the pressure gage plus the applied pressure in feet of water. See Figure 2-12.

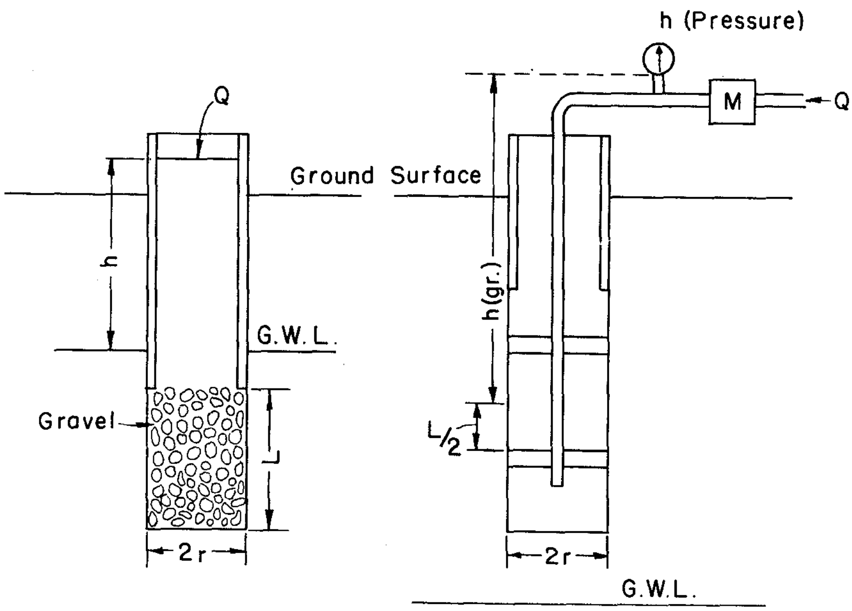


Figure 2-12 Packer-type Permeability Test

Where the length of the test section (L) is equal to or more than 5 times the diameter of the hole ($L \geqq 10r$), the formula used to compute permeability is:

$$k = \frac{Q}{2\pi Lh} \log_e \left(\frac{L}{r}\right) \qquad (4)$$

where,

k = permeability,

Q = constant rate of flow into the hole,

L = length of the test section,

h = differential head of water,

r = radius of test section

If the length of section being tested is less than five times the diameter, the relation is best described by changing the natural logarithm ($\log_e$) or $\frac{L}{r}$ in the above formula to the arc hyperbolic sine ($\sinh^{-1}$) of $\frac{L}{2r}$:

$$k = \frac{Q}{2\pi Lh} \sinh^{-1} \left(\frac{L}{2r}\right) \qquad (5)$$

Again, any consistent set of units can be used. If however, k is in cubic feet per square foot per day, Q in gallons per minute, and L, h, and r in feet, the formulas can be rewritten:

$$k = \frac{30.6Q}{Lh} \log_e \left(\frac{L}{r}\right) \qquad (6)$$

$$k = \frac{30.6Q}{Lh} \sinh^{-1} \left(\frac{L}{2r}\right) \qquad (7)$$

Table 2-2 below gives rounded values for the arc hyperbolic sines of numbers between 0.5 and 4.9. Table 2-3 gives rounded natural logarithms of numbers between 10 and 99. Other values can be obtained by interpolation.

Table 2-2 Arc Hyperbolic Sines of Numbers from 0.5 to 4.9

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0						.482	.569	.653	.733	.809
1	.88	.95	1.02	1.08	1.14	1.19	1.25	1.30	1.35	1.40
2	1.44	1.49	1.53	1.57	1.61	1.65	1.68	1.72	1.75	1.78
3	1.82	1.85	1.88	1.91	1.94	1.97	1.99	2.02	2.05	2.07
4	2.09	2.12	1.14	2.17	2.19	2.21	2.23	2.25	2.27	2.29

Table 2-3 Natural Logarithms of Numbers from 10 to 99

	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
10	2.30	2.39	2.48	2.56	2.64	2.71	2.77	2.83	2.88	2.94
20	2.99	3.04	3.08	3.13	3.17	3.21	3.26	3.29	3.33	3.36
30	3.39	3.43	3.46	3.49	3.52	3.55	3.58	3.61	3.64	3.66
40	3.69	3.71	3.74	3.76	3.78	3.80	3.83	3.85	3.87	3.89
50	3.91	3.93	3.95	3.97	3.99	4.00	4.02	4.04	4.06	4.07
60	4.09	4.10	4.12	4.14	4.16	4.17	4.19	4.20	4.22	4.23
70	4.25	4.26	4.27	4.29	4.30	4.31	4.33	4.34	4.35	4.37
80	4.38	4.39	4.40	4.42	4.43	4.44	4.45	4.46	4.47	4.49
90	4.50	4.51	4.52	4.53	4.54	4.55	4.56	4.57	4.58	4.59

Following is an example of the use of the above formulas and tables:

Given:

$r = 0.125$ ft

$L = 2.1$ ft $L > 10r$, use formula (6)

$h = h$ (gravity) + h (pressure)

h (gravity) = distance from ground water level or mid-point between packers to gage

= 3.7 feet

h (pressure)= 6 p.s.i. (gage reading)

= 13.9 feet (gage reading X 2.31)

= 3.7 + 13.9 = 17.6 feet

$Q = 3.6$ g.p.m.

$$k = \frac{30.6Q}{Lh} \log_e \left(\frac{L}{r}\right) \qquad (6)$$

$$L/r = \frac{2.1 \text{ ft}}{.125 \text{ ft}} = 16.8; \ \log_e 16.8 = 2.81 \text{ (from table 2-3)}$$

$$k = \frac{30.6 \times 3.6 \times 2.81}{2.1 \times 17.6} = 8.35 \text{ ft per day}$$

Well permeameter method - The open-end test and packer test described above are most practical in fairly permeable materials. That is, where the coefficient of permeability is one foot per day or greater. The well permeameter is best suited for low permeability materials. It is often useful in resevoir bottoms and canals to determine leakage potentials.

Since, in this test, the rate of inflow (Q) is usually very low, flow meters cannot be used and the volume of water used must be measured by some other method. An open-ended drum, calibrated in 1-gallon increments, is a convenient device. Also, since the test is of long duration and inflow rates are low, the water level must be maintained by use of a float valve. Any standard bob-float stock-watering valve with sufficient capacity to maintain the water level and with a counterbalanced operating arm can be used. The counter-balance allows the float to be suspended from the operating arm by means of a chain which can be lowered into the hole. The elevation of the water surface in the hole is controlled by the length of the chain. Figure 2-13 is an illustration of the test apparatus as it should be set up.

The hole for this test can be made by any convenient method, taking care that all compacted soil is removed from the side of the hole and that the bottom of the hole is clean. The hole can be of any desired dimensions as long as it conforms to the general rule that its depth should be between 10 and 150 times the radius.

After the hole is completed and cleaned, it is backfilled with a measured volume of clean, uniform, coarse sand or gravel to a level about 6 inches below the water level to be maintained. The sand serves the purpose of supporting the hole during saturation and is a means of determining the mean radius of the hole. The radius is computed as described under the section on packer tests. A short piece of galvanized casing should be placed above the sand as protection for the float. This casing should be smaller than the hole to allow water to move freely outside the casing to the elevation of the water level in the well. It can be held in place by pouring pervious sand between the outside of the casing and the well.

The water used in the test should be from the same source as the water which will permeate the strata after construction, if possible. This is because in some soils and waters, a base exchange reaction takes place which might increase or decrease permeability. If this does occur, using water from a common source will assure any change will be in the right direction. The water must be completely free from sediment. Its temperature should be slightly higher than the temperature of the soil or ground water to prevent the formation of air bubbles. Because of the wide range of temperatures at shallow depths, the results of this test must be corrected to a standard temperature. This may be either 20° C or 60° F. Therefore, the temperature of the water in the hole must be taken. If the test is of long duration, the temperature should be taken several times and averaged to make the correction. Table 2-4 lists the factors by which the results of the test must be multiplied to make the temperature corrections (C_t). The factors are derived by dividing the viscosity of water at the given temperature by the viscosity of water at standard temperature (20° C and 60° F).

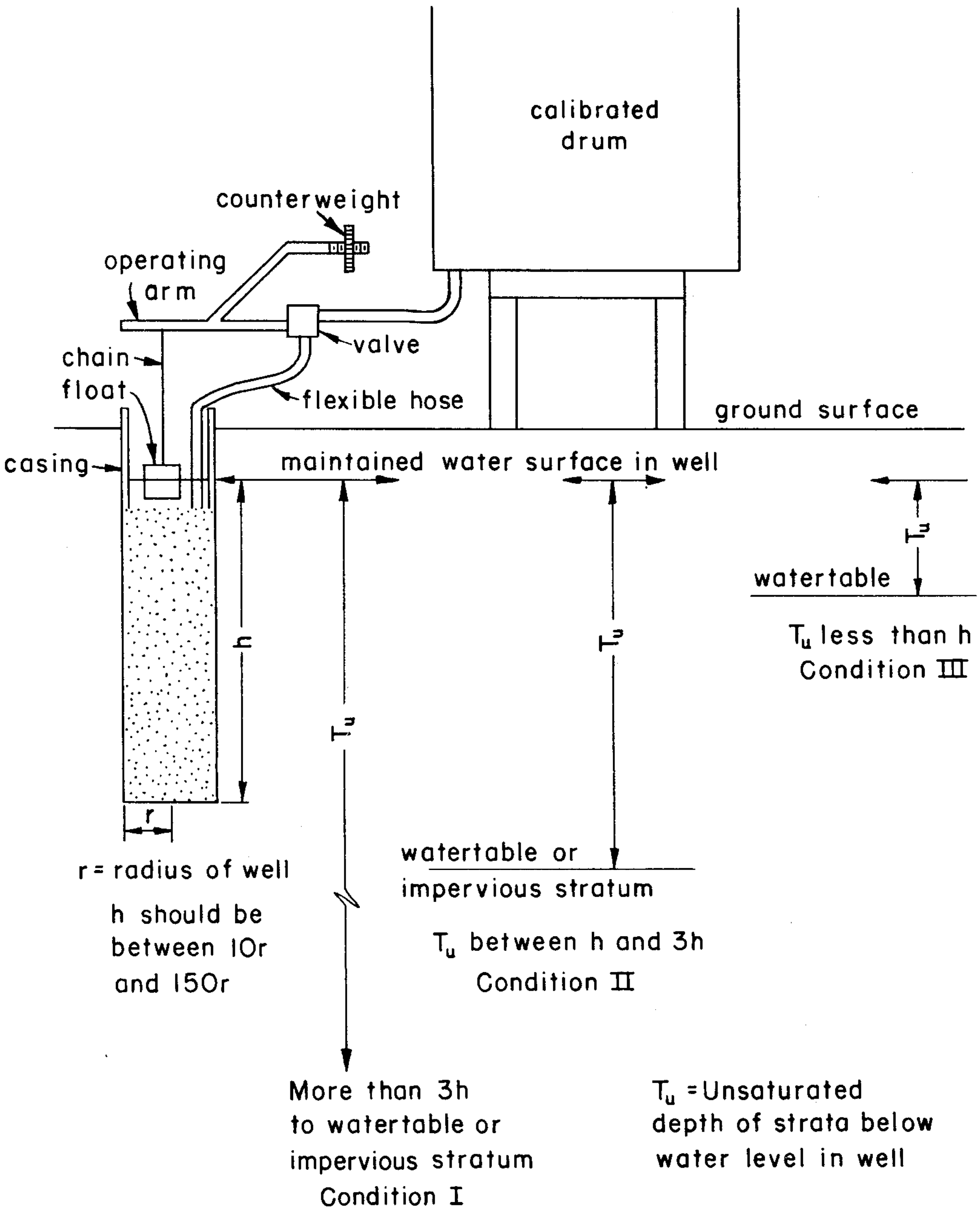


Figure 2-13 Well-permeameter Test

Table 2-4 Temperature Correction Factors

Water Temp. Degrees C	F	Correction Factor (C_t) to 20°C	60°F	Water Temp. Degrees C	F	Correction Factor (C_t) to 20°C	60°F	Water Temp. Degrees C	F	Correction Factor (C_t) to 20°C	60°F
10	50.0	1.30	1.17	17	62.6	1.08	0.97	24	75.2	0.91	0.82
11	51.8	1.27	1.14	18	64.4	1.05	0.94	25	77.0	0.89	0.80
12	53.6	1.24	1.11	19	66.2	1.02	0.92	26	78.8	0.87	0.78
13	55.4	1.20	1.08	20	68.0	1.00	0.90	27	80.6	0.85	0.76
14	57.2	1.17	1.05	21	69.8	0.98	0.86	28	82.4	0.83	0.75
15	59.0	1.13	1.02	22	71.6	0.95	0.85	29	84.2	0.81	0.73
16	60.8	1.10	0.99	23	73.4	0.93	0.84	30	86.0	0.80	0.71

The test should be run long enough to develop a saturated envelope in the soil around the well, but not long enough to build up the water table. In the more permeable materials the test should be run until a graph of time plotted against accumulative discharge for several hours is a straight line, indicating that a steady rate of discharge has been established. The straight portion of the curve should then be used for determining Q to compute permeability.

If a steady rate of discharge has not been established after approximately 8 hours, the minimum volume to be discharged can be determined from the following formula:

$$V_{min.} = 2.09\,Y_s \left[h \sqrt{\frac{2}{\sinh^{-1}\left(\frac{h}{r}\right) - 1}} \right]^3 \qquad (8)$$

where,

V_{min} = minimum volume to be discharged

Y_s = specific yield of soil being tested

h = height of water in well

r = radius of well.

The formula requires that the specific yield (Y_s) of the strata being tested be known. Specific yield is the amount of water which will drain from a soil by gravity flow. It is written as a decimal fraction of the saturated volume of the soil. For common soils, specific yields vary from 0.10 for fine grained soils to 0.35 for coarse grained soils. When the specific yield of the soil is not known, 0.35 should be used to give a conservative value for minimum volume. The test should be discontinued when the minimum volume has been discharged. Minimum volume can be determined from table 2-5, when h and r are known and specific yield is assumed to be 0.35. If the specific yield of the soil is known, the minimum volume determined from table 2-5, should be multiplied by the fraction $\frac{Y_s}{0.35}$ where Y_s is the known specific yield of the soil.

The field data needed to compute permeability are: (1) The rate of flow into the well in gallons per minute. (2) The mean radius of the well, in feet. (3) The height of the column of water in the well, measured from the bottom of the hole to the maintained water level, in feet. (4) The depth to the water table, if it is shallow, or the depth to an impervious layer or the water table (whichever is higher) if the water table is deep. (5) The temperature of the water in the well. The soil temperature should be determined also, to be sure that the water being used is warmer than the soil.

As illustrated in Figure 2-13, there are three different conditions which normally exist in the field. Each requires a slightly different formula for computing permeability.

Table 2-5 Minimum Volume, in Gallons, to be Discharged in Well Permeameter Where $Y_s = 0.35$

Radius of Well (r)		Height of Water in Well (h) Feet										
Inches	Feet	2	3	4	5	6	7	8	9	10	11	12
1.00	.083	25	70	145	265	410	620	900	1230	1620	2090	2660
1.25	.104	30	80	165	290	450	670	970	1310	1720	2220	2820
1.50	.125	35	85	180	310	480	720	1040	1390	1820	2350	2980
1.75	.146	35	95	195	335	510	770	1110	1470	1920	2480	3140
2.00	.167	40	100	210	355	550	820	1180	1550	2020	2600	3300
2.25	.187	40	110	220	380	580	870	1240	1630	2120	2720	3460
2.50	.208	--	115	235	400	610	910	1310	1710	2220	2840	3620
2.75	.229	--	125	250	420	640	960	1370	1780	2320	2960	3780
3.00	.250	--	130	260	440	670	1000	1430	1860	2410	3080	3940
3.25	.271	--	140	275	460	700	1050	1480	1930	2510	3200	
3.50	.292	--	145	290	480	730	1090	1540	2010	2610	3320	
3.75	.312	--	---	300	500	760	1130	1590	2080	2710	3440	
4.00	.333	--	---	315	520	790	1170	1640	2160	2800	3560	
4.25	.354	--	---	325	540	820	1210	1690	2230	2890	3680	
4.50	.375	--	---	340	560	850	1250	1740	2310	2980	3800	
4.75	.396	--	---	350	580	880	1290	1790	2380	3070		
5.00	.417	--	---		600	910	1330	1840	2450	3160		

Condition I exists when the distance from the water surface in the well to the water table or an impervious layer is greater than three times the height of water in the well. For this condition, equation (9) below, is used.

Condition II exists when the water table is below the bottom of the well, but the depth to the water table or an impervious layer is less than three times the height of water in the well. For this condition, equation (10) below, is used.

Condition III exists when the water table is above the bottom of the well. Equation (11) is used in this case.

Equation for condition I:

$$k = \frac{192\left[\sinh^{-1}\left(\frac{h}{r}\right)-1\right]\frac{Q}{2\pi}}{h^2}\,C_t \qquad (9)$$

Equation for condition II

$$k = \frac{192\,\log_e\left(\frac{h}{r}\right)\frac{Q}{2\pi}}{h^2\left(\frac{1}{6}+\frac{T_u}{3h}\right)}\,C_t \qquad (10)$$

Equation for condition III

$$k = \frac{192\,\log_e\left(\frac{h}{r}\right)\frac{Q}{2\pi}}{h^2\left(\frac{T_u}{h}-\frac{T_u^2}{2h^2}\right)}\,C_t \qquad (11)$$

where,

k = coefficient of permeability, cubic feet per square foot per day,

h = height of water in well, feet, measured from the bottom of well to maintain water level,

r = radius of well, feet,

Q = constant rate of flow into hole, gallons per minute,

T_u = unsaturated thickness between water level in the well and the water table or impervious layer,

C_t = correction to standard temperature.

Following are examples of each of the three conditions using the appropriate equation:

Condition I, where T_u is greater than 3h.

Given:

h = 5 feet

r = 0.125 feet

Q = 0.10 gallons per minute

T_u = 30 feet (greater than 3h; use equation 9)

T = temperature of water in well = 18° C

$$k = \frac{192 \left[\sinh^{-1}\left(\frac{h}{r}\right) - 1\right] \frac{Q}{2\pi}}{h^2} C_t \qquad (9)$$

$$\frac{h}{r} = \frac{5 \text{ ft}}{0.125 \text{ ft}} = 40; \ \sinh^{-1} 40 = 4.37$$

$$k = \frac{192 \text{ X } (4.37-1)}{25} \text{ X } 1.05 = 0.43 \text{ ft}^3/\text{ft}^2/\text{day}$$

The arc hyperbolic sines for $\frac{h}{r}$ from 10 to 200 can be obtained from table 2-6.

Table 2-6 Arc Hyperbolic Sines

	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
10	3.00	3.10	3.18	3.26	3.34	3.41	3.47	3.53	3.59	3.64
20	3.69	3.74	3.79	3.83	3.88	3.92	3.96	3.99	4.03	4.07
30	4.10	4.13	4.16	4.19	4.22	4.25	4.28	4.30	4.33	4.35
40	4.37	4.40	4.42	4.45	4.48	4.50	4.53	4.55	4.57	4.59
50	4.61	4.63	4.65	4.67	4.69	4.71	4.72	4.74	4.75	4.77
60	4.78	4.80	4.81	4.83	4.84	4.86	4.87	4.89	4.91	4.93
70	4.94	4.95	4.97	4.98	4.99	5.01	5.02	5.04	5.05	5.07
80	5.08	5.09	5.10	5.12	5.13	5.14	5.15	5.16	5.17	5.18
90	5.19	5.20	5.21	5.22	5.23	5.24	5.25	5.26	5.27	5.28
100	5.29									
200	5.99									

Example two:

Condition II, where T_u is greater than h but less than 3h.

Given:

h = 5 feet

r = 0.125 feet

Q = 0.10 gallons per minute

T_u = 6 feet (greater than h but less than 3h; use equation 10)

T = 18° C.

$$k = \frac{192 \log_e\left(\frac{h}{r}\right)\frac{Q}{2\pi}}{h^2\left(\frac{1}{6}+\frac{T_u}{3h}\right)} C_t \qquad (10)$$

$\log_e 40 = 3.69$

$$k = \frac{192 \times 3.69 \times \frac{0.10}{6.28}}{25 \ \left(\frac{1}{6}+\frac{6}{15}\right)} \times 1.05 = 0.84 \ ft^3/ft^2/day$$

The natural logarithms of h/r are obtained from table 2-3.

Example three:

Condition III, where T_u is less than h:

Given:

h = 5 feet

r = 0.125 feet

Q = 0.10 gallons per minute

T_u = 3 feet (less than h; use equation 11)

T = 18° C

$$k = \frac{192 \log_e\left(\frac{h}{r}\right)\frac{Q}{2\pi}}{h^2\left(\frac{T_u}{h}-\frac{T_u^2}{2h^2}\right)} C_t \qquad (11)$$

$$= \frac{192 \times 3.69 \times \frac{0.10}{6.28}}{25\ (\frac{3}{5} - \frac{9}{50})} \times 1.05 = 1.13\ ft^3/ft^2/day$$

Soil-sampling Tools

General

A wide variety of cutting and sampling tools are available on the market. Tables 2-7 and 2-8 may be used as a guide in selecting tools for drilling, logging, and sampling purposes in various soils. Only those logging and sampling tools recommended for SCS use are discussed in this Handbook.

Open-drive and Piston Samplers

Open-drive samplers are cylindrical samplers which are pushed or driven into the materials to be sampled. A drive sampler equipped with a piston is known as a piston sampler. A large number of drive and piston samplers are available on the market. They are manufactured in a variety of diameters, tube thicknesses and tube lengths. They are generally known as thick wall, thin wall, and split barrel samplers.

Thin-wall Open-drive Samplers

Thin-wall open samplers consist of solid thin-wall barrels. These are manufactured in a variety of lengths, diameters, and wall thicknesses. They must be equipped with ball or other types of check valves for satisfactory performance.

The simplest type of open drive sampler is the so-called thin-wall "Shelby Tube," Figure 2-14. It should be obtained in steel tubing lengths of 24 inches and from 3½ to 5 inches in diameter. The tube is attached to a head assembly by means of set screws. This head assembly contains a ball check valve. After the sample is obtained, the tube is detached from the head, sealed, and shipped to the laboratory where the sample is removed for conducting tests.

Thin-wall samplers do not have cutting shoes but rather a sharpened cutting edge. To provide clearance in certain materials, the edge may be swaged to cut a sample smaller than the inside diameter. Table 2-9 lists recommended bit clearance for different types of material.

Thin-wall drive-samplers provide good undisturbed samples of certain soil materials if proper methods of operation are used. The sampler must be advanced by a uniform and uninterrupted push without rotation. No additional drive should be made after the sampler stops. This requires that the drill rig be provided with a hydraulic pressure device capable of exerting a driving force of at least 8000 pounds. Since the drill rig serves as a reaction for driving the sampling tube, it may be necessary to anchor the rig to hold it down.

Sampler	Minimum Diameter[1] Required for:						Materials in Which Used
	Hole advancement	Logging	Consolidation Tests[2]	Direct Shear	Triaxial Shear	Horizontal Permeability	
Continuous Helical Augers	3 O.D.						Medium soft to stiff cohesive soils free of cobbles and boulders. Unsaturated but wet sand and silt.
Iwan Hand Augers	2 O.D.	2[3]					
Closed Bucket Augers	3 O.D.	3 O.D.[3]					All, including gravel. Free of cobbles and boulders.
Slat-type Bucket Augers	3 O.D.	3 O.D.[3]					Cohesive soils.
Split-barrel		1-3/8[4]					All but hard and brittle soils free of coarse gravel, cobbles and boulders.
Dry-barrel	3 O.D.	3 O.D.					Cohesive soils.
Thin Wall		3	3	3	3-5[5]	5	Soft to stiff and loose to medium.
Stationary Piston-Thin Wall		3	3	3	3-5[5]	5	Same as above but includes very soft and very loose soils
Chopping-Jetting	2 O.D.						Stiff to hard clays, brittle soils, dense sand, partially cemented soils. All but very soft soils.
Double Tube Soil Core Barrel (Denison)	4 O.D.	2-15/16	2-15/16	2-15/16	3-5[5]	5	
Roller Bit	3 O.D.						Hard to soft rock.
Double-Tube Rock Core Barrel	2-15/16 O.D.	2-1/8	2-1/8	2-1/8	2-1/8	2-1/8	

1/ Applies to inside diameter unless indicated otherwise.
2/ Includes vertical permeability tests.
3/ Recommended only for use in homogeneous materials.
4/ Also standard penetration test.
5/ Three-inch samples are suitable when foundation materials are relatively homogeneous. Five-inch samples are required when stratification of the profile is significant.

Table 2-7 Recommended Logging and Sampling Tools, with Minimum Diameter

Table 2-8 Soil Types and Sampling Tools

Type of Soil	Logging or Disturbed Samples	Undisturbed Samples
Common cohesive and plastic soils.	Bucket-type augers,1/ all types of drive samplers, dry barrel.	Thin-wall open-drive sampler. Piston sampler. Double-tube core barrel
Slightly cohesive and brittle soils including silt, loose sand above the water table.	Same as above.	Thin-wall open-drive samplers. Piston samplers below water table. Double-tube soil core barrel (with liner).
Very soft and sticky soils.	Closed bucket auger,1/ dry barrel, piston sampler or open drive with core retainers.	Thin-wall or piston samplers.
Saturated silt and loose sand.	As above. Overdrive push-tubes to retain sample.	Piston sampler with heavy mud.
Compact or stiff and brittle soils including dense sands, partially dried soils.	Bucket-type auger.1/ Thick-wall drive sampler.	Double-tube soil core barrel.
Hard, highly compacted or partially cemented soils, no gravel or cobbles.	Bucket auger.1/ Thick wall drive sampler and hammer. Double-tube core barrel	Double-tube soil core barrel.
Coarse, gravelly and stony soils including compact and coarse till.	Bucket auger1/ 2/ Large diameter thick wall drive sampler.	Not practical. (Advance freezing and core.)
Organic clay, silt or sand.	As above according to basic soil type.	Thin-wall piston. Measure length of drive and original volume of sample carefully.

1/ Homogeneous soils only.

2/ Power equipment such as bulldozers and backhoes are more suitable in many cases.

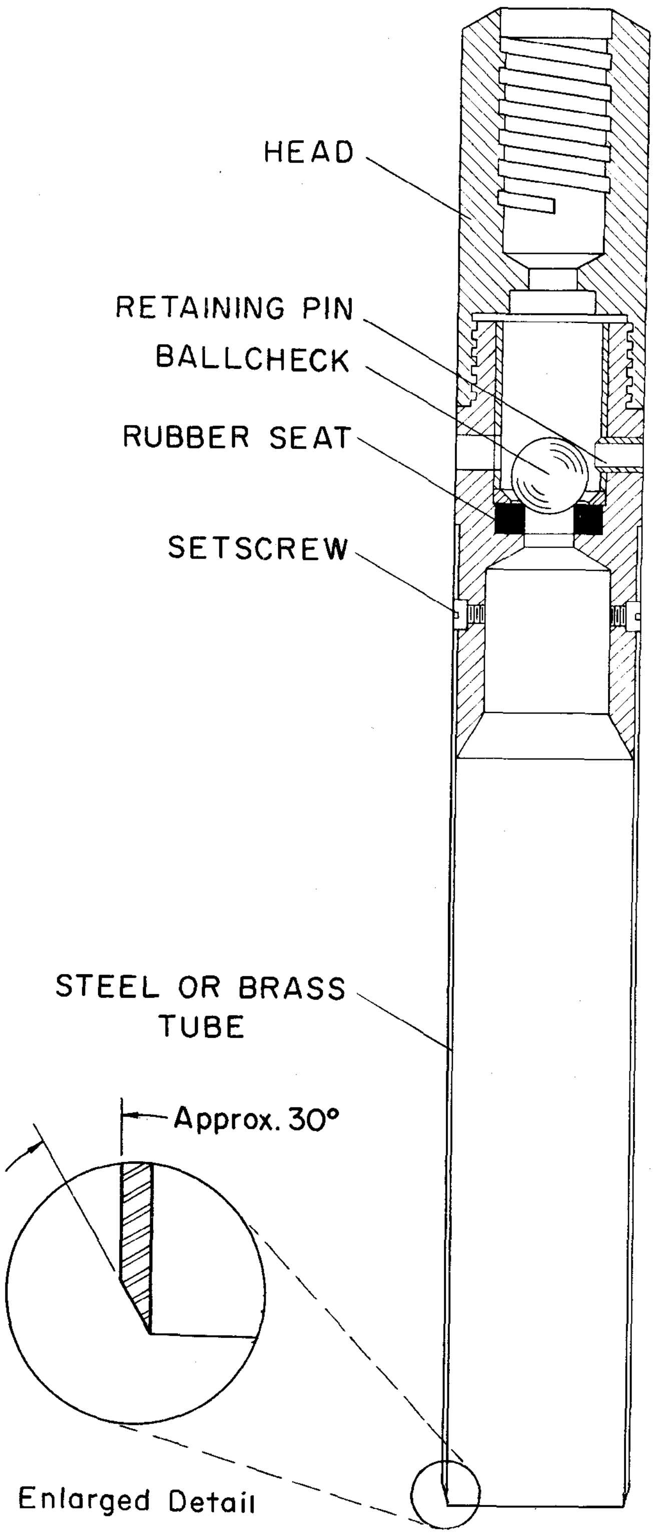


Figure 2-14 Thin-wall Open Drive Sampler

Thin-wall drive sampling methods are most practical in fine-grained, plastic, or peaty soils. The method is not suited for sampling brittle, cemented, or gravelly soils. The amount of disturbance in drive samples depends to a great extent on the dimensions of the sample tube. The thinner the wall and the larger the diameter, the less the disturbance will be.

Extruded samples are excellent for logging purposes. If desired for this purpose, the drill rig must be equipped with a sample ejector. The sample should be extruded through the top of the sampler.

Undisturbed samples for laboratory analysis should not be removed from the sampling tube in the field, but should be sealed in the tube and the tube sent to the laboratory. Either 3-inch or 5-inch diameter undisturbed samples should be taken depending upon the type of laboratory test desired.

Three-inch diameter tubes usually have a wall thickness of 1/16 inch and 5-inch diameter tubes about 1/8 inch. These tubes have no cutting shoe. Equipment is available to swage thin-wall tubes to provide desirable bit clearance. Bit clearance refers to the difference between the diameter of the cutting edge and the inside diameter of the sampling tube, in percent. For example, if the cutting edge is 2-15/16 inches and the I.D. of the sampling tube is three inches, then the bit clearance is 3 minus 2-15/16 divided by 3 (I.D.), or about 2 percent. Bit clearance may not be necessary if use of the sampler is limited to soft, loose, non-cohesive materials. Tubes with the proper bit clearance should be available at the site to obtain adequate undisturbed samples for each type of material encountered. Cohesive soils and soils which are slightly expansive require varying amounts of bit clearance. Saturated and soft, loose sands, silts and some clays may require little or no clearance. The clearance selected is that necessary to minimize drag or sidewall friction on the sample and to assist in retaining the sample in the tube.

Thin-wall sampling procedure.--The basic procedures for thin-wall tube sampling are as follows:

1. Advance hole to strata to be sampled.

2. Clean hole thoroughly to remove loose material from the bottom.

3. Be sure drilling rig is anchored or heavy enough to counteract the pressure it is capable of exerting. This should be at least 8000 pounds.

4. Sample tube must be smooth, thoroughly cleaned inside and outside, be properly sharpened, and have correct bit clearance for the type of soil being sampled. (See Table 2-9). Tubes should be plastic coated or greased to prevent rusting.

Table 2-9 General recommendations for thin-wall drive sampling

Soil type	Moisture condition	Soil consistency	Length of drive, inches	Bit clearance, percent	Open-drive sampler recovery	Recommendations for better recovery
Gravel..........	(Thin-wall drive samplers not suitable)					
Sand............	Moist...............	Medium............	18................	0 to ½..........	Fair to poor......	
Sand............	Moist...............	Loose.............	12................	½...............	Poor..............	Recommend piston sampler.
Sand............	Saturated...........	Medium............	18................	0...............	Poor..............	Recommend piston sampler.
Sand............	Saturated...........	Loose.............	12 to 18..........	0...............	Poor..............	Recommend piston sampler.
Silt............	Moist...............	Firm..............	18................	½...............	Fair to good......	
Silt............	Moist...............	Soft..............	12 to 18..........	½...............	Fair..............	
Silt............	Saturated...........	Firm..............	18................	0...............	Fair to poor......	Recommend piston sampler.
Silt............	Saturated...........	Soft..............	12 to 18..........	0 to ½..........	Poor..............	Recommend piston sampler.
Clay and shale...	Dry to saturated.....	Hard..............	(Thin-wall drive sampler not suitable)..................			Recommend double-tube sampler.
Clay............	Moist...............	Firm..............	18................	½ to 1..........	Good..............	
Clay............	Moist...............	Soft..............	12 to 18..........	1...............	Fair to good......	
Clay............	Saturated...........	Firm..............	18................	0 to 1..........	Good..............	
Clay............	Saturated...........	Soft..............	18................	½ to 1..........	Fair to poor......	Recommend piston sampler.
Clay............	Wet to saturated.....	Expansive.........	18................	½ to 1½.........	Good..............	

Adapted from U.S.B.R. Earth Manual, 1960.

5. Attach tube to drill rod and lower into hole until it rests on the bottom.

6. Drive must be made without rotation and with one continuous stroke.

7. Length of drive must be carefully measured and should be a few inches short of the sampler length to prevent compaction of the sample in the tube by over driving. See Table 2-9.

8. Rotate sampler slightly to break off sample before pull is started.

9. Retrieve sampler from hole carefully and with a steady pull to avoid sample loss.

10. Length of sample recovered must be accurately measured and recorded.

11. Samples are sealed in tube for handling and shipping.

Piston-drive Samplers

Piston samplers are thin-wall samplers similar to "Shelby" thin-wall samplers but containing a piston to facilitate sampling. It is designed to obtain samples of soft or medium soils and for obtaining samples of sands, silts, and cohesive soils below the water table. See Tables 2-7 and 2-8. The stationary-piston sampler (Figure 2-15) is lowered to the bottom of the bore hole with the piston held in the lower end of the sampler. The piston is then locked into position by means of actuating rods which extend to the surface within the drill rods. The tube is then forced into the materials by steady pressure, while the piston remains stationary at constant elevation, to obtain the sample. The sampler is equipped with a vented head to permit escape of air above the piston. The piston creates a vacuum which holds the sample in the tube while it is being brought to the surface.

Stationary-piston samplers are available in sizes up to 30 inches in length with I.D. up to 4-3/8 inches. A modification of the above sampler (Osterberg type) requires lowering of the sampler in the bore hole and forcing the sampling tube into materials by means of hydraulic pressure applied through the drill rods. This type of sampler is available in 3-inch and 5-inch diameters. This type of sampler is recommended for those soils requiring a piston sampler.

Piston sampling procedure--The basic principles of operation for stationary-piston sampling are the same as for thin-wall sampling with the exception of techniques for locking the piston which vary with the type of sampler. Additional considerations are as follows: (1) The hydrostatic pressure of drilling fluids aids the suction effect of the piston. The consistency of the mud should be such

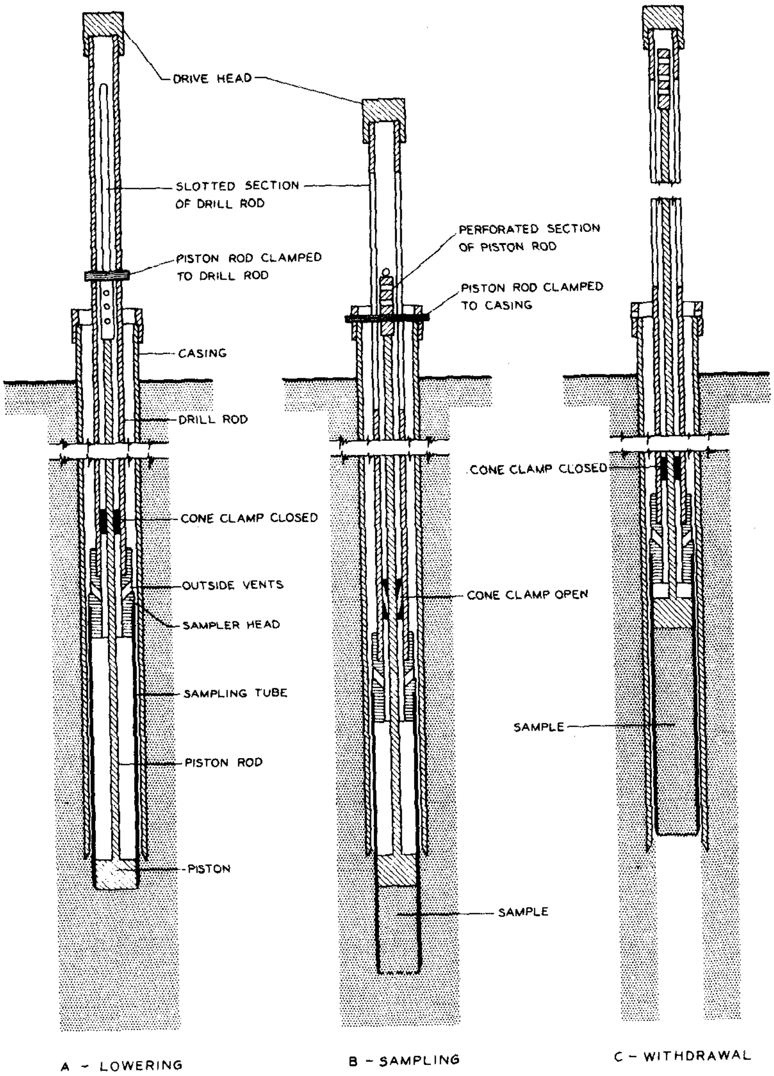


Figure 2-15 Stationary-Piston Sampler

that about ½ inch of the sample is saturated with mud; and, (2) tubes have little or no bit clearance and no sample retainers.

The basic procedures for sampling with the stationary piston sampler are as follows:

1. Advance and clean hole to sampling horizon as in open thin-wall drive sampling.

2. Attach sampler to drill rod.

3. Insert the piston and lock flush with the bottom of the tube.

4. Where a piston rod is used, it is connected to the piston either after the sampler has been lowered to the bottom of the hole or it may be connected piece by piece inside the drill rod while the sampler is being lowered.

5. The sampler is placed at the bottom of the bore hole and the piston unlocked by turning the piston rod clockwise five revolutions (this may vary with different samplers.)

6. The piston rod is then secured to the drill rig, casing, or preferably to an independent frame and the sampler injected under steady pressure into the material to be sampled. Weight of equipment is normally used as the reacting force.

7. Carefully measure length of drive.

8. At the end of the drive the piston rod is disconnected by continuing to turn it clockwise until the rod is fully released, then the sampler is raised. The piston is held in place at the top of its stroke by a split-cone clamp.

9. Before removing the sampler from the drilling fluid at the ground surface, the hand or a block should be placed over the end to prevent the sample from dropping out.

10. Remove sampling tube from drill rod and measure and record length of sample.

11. Seal sample in tube for shipment to the laboratory.

<u>Split-barrel Sampler</u>

The split-barrel sampler (Figure 2-7) consists of a head, barrel and cutting shoe. The barrel is split longitudinally so that it can be taken apart, after removal of the head and the shoe, and the sample removed for visual inspection or packing in jars or other containers for shipment to the laboratory. The split-tube sampler can withstand hard driving into soil materials. Since cutting shoes often become damaged by driving, a supply of additional cutting shoes should always be available in the field.

Split-tube samplers may be obtained in lengths up to 24 inches. The 2-inch O.D. sampler is recommended for logging purposes and is required for the standard penetration test. It is not suitable for taking an undisturbed sample because of sample disturbance due to the thick cutting shoe and driving action of the hammer. Split-barrel samplers are adapted for accurate logging of thin-bedded materials.

Split-barrel sampling procedures--Sampling and standard penetration tests are normally run in conjunction with each other. Procedures for sampling and running standard penetration tests are as follows:

1. Advance and clean out hole to horizon to be logged.

2. Attach split-barrel sampler to drill rod and lower to bottom of hole. Sampler must be 2 inch O.D. and 1 3/8 inches I.D. of the cutting edge for standard penetration test.

3. Drive sampler 6 inches into strata and mark drill stem with chalk to provide for 1-foot drive.

4. With 140-pound drive hammer, falling 30 inches, drive sampler for distance of 12 inches. Count and record number of blows required for each 6 inches of this 12-inch test.

5. Rotate sampler slightly to break off before pull is started and retrieve sampler.

6. Remove sampler from rod and disassemble by removal of cutting shoe, head, and separating the two halves of the barrel.

7. Carefully log sample and record length.

8. Place samples needed for laboratory analyses in sealed jars to retain natural moisture.

9. Clean, inspect, and reassemble sampler for next drive. If cutting shoe has been damaged by the previous drive to the extent that the inside diameter is appreciably altered, it must be replaced with a proper cutting shoe.

<u>Double-Tube Soil Core Barrel Sampler (Denison Type)</u>
The most satisfactory sampler for obtaining nearly undisturbed soil samples of highly compacted, hard, stiff, uncemented or slightly cemented materials is the double-tube soil core barrel

with liner (Figure 2-16). Samples of cohesive soils are obtained with a double-tube soil core barrel with the least amount of disturbance. Double-tube samplers can be used to sample a wide variety of materials including some rock such as soft shales and soft and friable sandstones. The method is not satisfactory for obtaining undisturbed samples of soft, loose, cohesionless silts and sands below the water table, or very soft and plastic cohesive materials where the structure is destroyed by barrel whip. It is not suitable for obtaining undisturbed samples of gravels and cobbles.

The double-tube core barrel is advanced by rotating the outer barrel which cuts a circular groove and loosens the soil material to be displaced by the two barrels. Drilling fluid is forced downward through the drill stem between the barrels and carries the cuttings to the surface outside the tubes and drill stem. The inner barrel which does not rotate, moves downward over the undisturbed sample being cut by the rotating outer barrel. A liner is inserted in the inner barrel before the barrel is assembled. After drilling the required length, the sampler is withdrawn and the liner removed and prepared for shipping.

The outer cutting bit or the inner cutting shoe of double-tube soil core barrels are made in several lengths so that the relation of the cutting edge of the inner barrel to the bit can be varied. A retracted inner shoe or long outer bit is used for very hard soils which are not subject to erosion. In dense or brittle soils, a short bit is used so that the inner barrel is nearly flush with the cutting teeth. Soft, loose, or slightly cohesive soils require the shortest bit and the maximum protrusion of the inner barrel so that the drilling mud does not wash out, penetrate, or undercut the sample. The sample should enter the barrel so that it fills the liner but the outer barrel should cut the core so that a minimum of downward pressure is required. The number of teeth of cutting bits varies from 6 to 24, their height from 1/8 to two inches, and the outward projection from 1/16 to 1/2 inch. Systematic experimentation to determine the optimum number, shape, and dimension of the teeth for various types of soils is needed, and consideration may be given to teeth with the cutting edge or face at an angle with the radius, so that the teeth will tend to carry the cuttings toward the outer rim of the bit. Often blank bits are furnished by the manufacturer. These are cut, shaped, and built up with a hard alloy as desired.

Basket or spring-type core retainers may be used. Several types, using a different number and flexibility of springs, are available for use in different materials. The tapered, split-ring core retainer used in rock core barrels is not satisfactory for use in soil. A check valve is provided to relieve pressure over the core. The coring bits used usually have hard surfaced steel teeth.

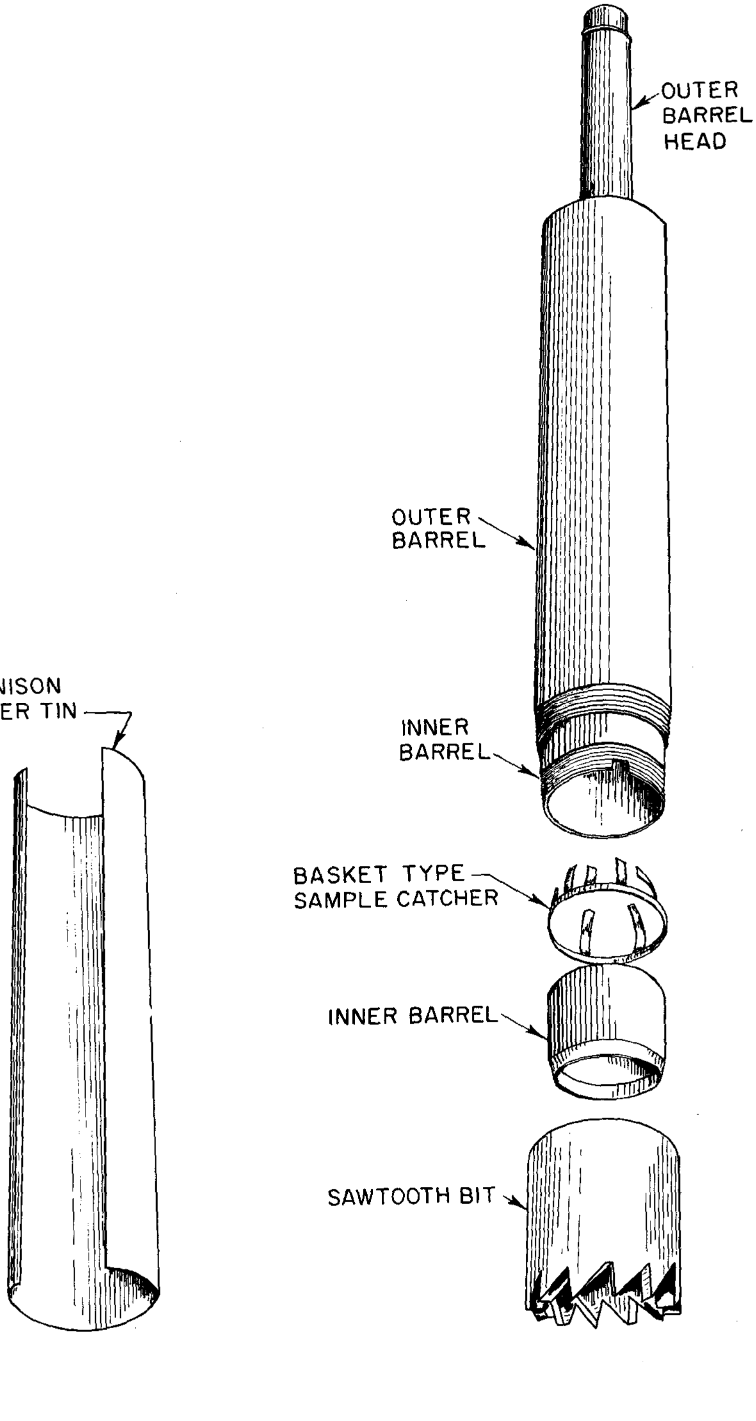


Figure 2-16 Double-tube Soil Core Barrel (Denison)

Double-tube soil core barrels with liners come in various sizes which obtain untrimmed soil samples ranging from 2-3/4 inches to 6 inches in diameter. The diameter of undisturbed core needed depends upon the kind of laboratory test required. Core barrels which obtain undisturbed samples of about two feet in length are recommended.

Sectional liners are recommended for use in denison-type core barrels when taking undisturbed samples for laboratory analysis. They should be made of stainless steel, preferably seamless, of cylindrical shape. Sectional liners, 8 inches long and 1/32 inch thick, are available from equipment manufacturers. A welded side joint is satisfactory if seamless construction is not available. Samples may be extruded at the laboratory from such liners with a minimum degree of disturbance and the liners returned to the field for reuse.

When sectional liners are used, three sections are taped together and placed in the barrel. The tape facilitates removing the sections from the barrel after sampling and also prevents water from entering between the sections and washing away the sample. The I.D. of the liners must be 1/8 inch smaller than the I.D. of the inner barrel on the sampler to be used, to allow clearance for the tape. A strong tape is needed to tape the sections together. GSA No. 8135-582-4772 is recommended. This type has longitudinally aligned filaments in the adhesive and has a tensile strength of 300 pounds per inch of width.

Two-foot, 20-gage galvanized metal liners may also be used to take samples for laboratory analysis. They should have welded and soldered seams. Split-tin liners or liners with loosely crimped seams are satisfactory for field logging purposes. The I.D. of the shoe on the inner should be machined or swaged down to 1/16 inch less than the I.D. of the liner, so that the sample will easily enter the liner.

Bit speed--Operational procedure in soil coring must be determined by trial for each soil condition. The rate of penetration, the speed of rotation, the length of cutting bit, the consistency of the drilling mud, and the pump pressure are all dependent upon soil conditions. The speed of rotation for soils and soft rock may vary from 40 to 125 rpm.

Bit pressure--The pressure on the coring bit and its rate of advance or feed must be carefully adjusted in accordance with the character of the material encountered, type of bit, and bit speed. Too high a bit pressure and rate of feed may damage the bit and cause plugging of the bit and fluid passages and failure of the sample before it enters the barrel. Too low a bit pressure and slow or intermittent feed may expose the core to excessive erosion and torsional stresses. As the sample enters the inner barrel, wall friction increases, and bit pressure must be increased to maintain a constant rate of advance. Generally, the rate of penetration should be no greater than the speed at which the outer barrel is able to cut.

A technique which assists in recovering a double-tube sample in materials of low cohesion is to shut off the circulating pump about two inches before the end of the drive. With the circulation shut off, the coring operation is completed. The soil will be forced up between the inner and outer barrels. This causes the inner barrel to turn with the outer barrel and shears off the core. Consequently, there is no tendency for the sample to be pulled out of the barrel by material to which it is attached at the base when the sampler is removed from the hole. This procedure will also result in compaction in the inner barrel shoes and form a plug which will assist in sample recovery. The core catcher normally is not required when this technique is used.

Double-tube soil core barrel sampling procedures-- The basic rules of operation for double-tube soil core barrels are as follows:

1. Assemble barrel, attach to drill rod, and lower to bottom of hole.

2. Initiate drilling mud circulation and rotation of barrel. Both bit speed and rate of drilling mud circulation should be increased slowly to their optimum rates.

3. Length of drive must be carefully measured. Total drive length should be a few inches shorter than the sample container length to prevent overdrive.

4. Downward force should be a minimum and regulated to that speed at which the outer barrel is able to cut.

5. The rotation of the bit should be limited to a speed which will not tear or break the sample.

6. The consistency of the drilling mud should be thick enough to prevent caving of the hole.

7. Pump pressures should be the minimum required to carry the cuttings from the hole.

8. The sampler should be withdrawn from the hole carefully so as not to disturb the core during withdrawal.

9. Disassemble barrel and remove sample liner with sample.

10. Carefully remove all disturbed materials from both ends of the liner.

11. Seal ends for shipment to the laboratory.

Rock-sampling Tools

Double-Tube Rock Core Barrel Sampler

General--Rock core barrels are of two types, single tube and double tube. The single tube is designed primarily for boring in sound rock or for taking large cores in all types of rock. Double-tube rock core barrels are particularly useful for drilling small holes in sound rock, for drilling fissured rock, and for drilling soft rock where the core needs to be protected from the erosive action of drilling water. The fluid passes between the inner and outer barrels eliminating its erosive action. There are two types of double-tube core barrels, "rigid" and "swivel." In the rigid type the inner tube and outer tube rotate together while in the swivel-type double-tube core barrel, the inner tube does not rotate. The double-tube rock barrel (Figures 2-17, 2-18) differs from the soil-coring barrel in that it does not have a removable liner to hold the sample, and in the relationship of the cutting shoe to the inner shoe. The cutting shoe trims the core at slightly less than that of the inner barrel and the sample is retained in the inner barrel by means of a core catcher. The rock core barrel obtains a sample of rock in the shape of a cylindrical core. The circular bit cuts the core and the barrel slides down over it. A ball-check valve to relieve water pressure, and a core catcher assist in retaining the core in the barrel. Table 2-10 lists the various sizes of coring bits and barrels used in SCS work. A double-tube swivel-type core barrel in NX size is recommended for the types of rock boring generally required in SCS work. With some types of drilling rigs a short barrel, taking a one-foot core, is useful for starting a bore hole where rock outcrops at the surface and cores are desired from the surface down. (Figure 2-18)

Rock core barrels may have either the "retracted inner barrel" or the "bottom discharge bit." In the retracted inner barrel the drilling water passes down between the inner and outer barrels, across the cutting teeth of the metal bit or the waterways of the diamond bit and up outside the outer barrel. It is used in non-erodible rock. In the bottom discharge bit the drilling fluid passes out through holes in the bottom of the bit proper, and thence up outside the outer barrel. It is used mainly in soft or broken rock.

Rock core bits--In general, a small number of relatively long teeth are preferable for coring soft rock formations such as those containing clay streaks or shale layers. On the other hand, a large number of small teeth provides a greater rate of progress and causes less disturbance of the material when coring in medium-hard formations.

Steel saw-tooth coring bits are usually provided with teeth or inserts made of very hard and abrasion-resistant tungsten carbide alloys which are sold under various trade names. Blank bits are also available for customers who desire to set their

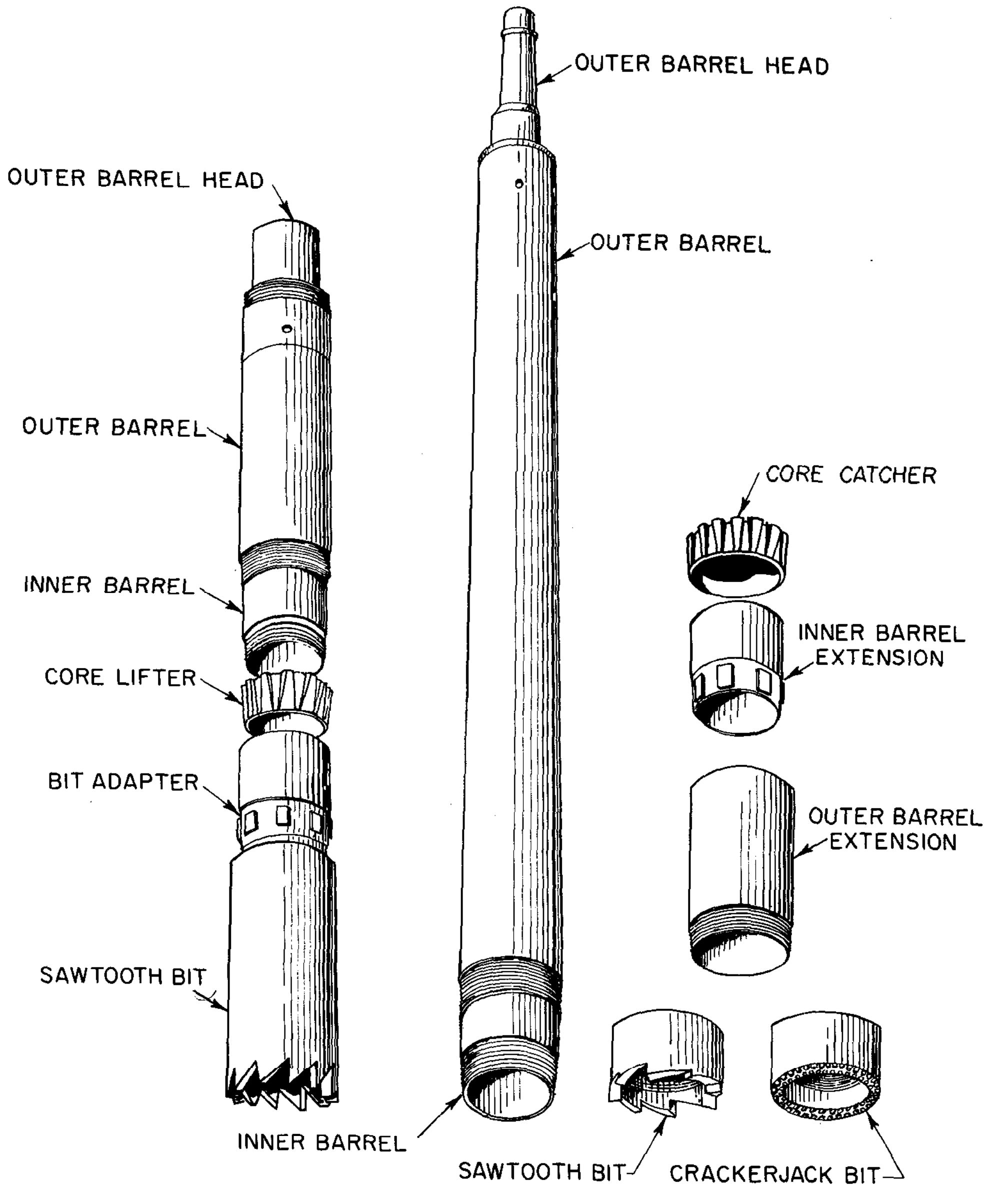


Figure 2-17 Long and Short Rock Core Barrel

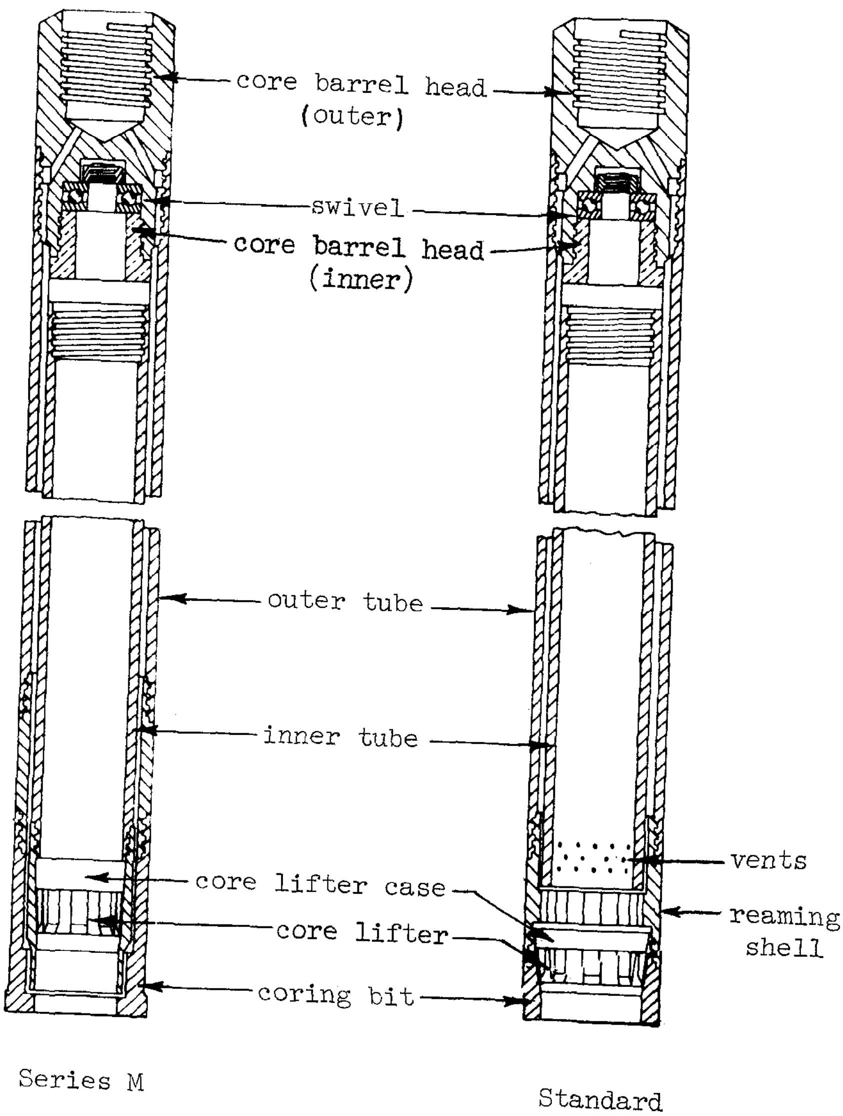


Figure 2-18 Swivel-type Double-tube Rock Core Barrels.

Table 2-10 Standard Sizes of Coring Bits and Barrels, Casing and Drill Rod.

ROCK AND SOIL CORING BITS AND BARRELS

Size Inches	Hole Inches	Core Inches
AX or AWX	1-7/8	1-1/8
BX or BWX	2-3/8	1-5/8
NX or NWX	2-15/16	2-1/8

FLUSH COUPLED CASING AND COUPLING

CASING				COUPLING			
Size	O.D. Inches	I.D. Inches	Wgt. lbs. per ft.	Size	O.D. Inches	I.D. Inches	Wgt.
AX	2-1/4	2	2.9	AX	2-1/4	1-29/32	1.8
BX	2-7/8	2-15/32	5.7	BX	2-7/8	2-3/8	3.2
NX	3-1/2	3-1/16	7.8	NX	3-1/2	3	4.0

DRILL ROD				DRILL ROD COUPLING			
Size	O.D. Inches	I.D. Inches	Wgt. lbs. per ft.	Size	O.D. Inches	I.D. Inches	Wgt.
A	1-5/8	1-1/8	3.7	A	1-5/8	9/16	1.7
AW	1-3/4	1-7/16	4.2	AW	1-3/4	5/8	2.2
B	1-7/8	1-1/4	5.0	B	1-7/8	5/8	2.4
BW	2-1/8	1-13/16	5.3	BW	2-1/8	3/4	3.1
N	2-3/8	1-5/8	5.2	N	2-3/8	1	4.0
NW	2-5/8	2-5/16	5.5	NW	2-5/8	1-3/8	5.5

(From The Diamond Core Drill Manufacturers Association) own bits. Steel bits are much less expensive than diamond bits, but are recommended for use only in soft or moderately soft rock. The rate of progress in hard rock is slow with steel bits and the bits wear rapidly.

Diamond bits are used for coring all but the soft and moderately soft rock. They are of two kinds - set and impregnated. In set bits, industrial diamonds, usually West African Bortz, are set by hand or machine in a tungsten carbide matrix metal. Reaming shells serve to stabilize the bit and prevent it from whipping from side to side. Diamond bits and reaming shells may be used interchangeably with steel bits on the double-tube rock core barrels. When set diamond bits and reaming shells become worn, they are returned to the manufacturer for resetting. The remaining stones are salvaged in this process.

Normally it is advantageous to have at least three types of diamond (set) bits available: One for very hard formations (chert or quartzite), one for hard formations (sandstone or dolomite), and one for medium hard formations (cemented shale). Bits for harder formations use smaller stones, greater total weight of stones, and less water courses. Using each bit only in the formations for which it is designed results in much longer life for the bits. Typical diamond bits and reaming shells are shown in Figure 2-19.

In impregnated bits the entire cutting edge of the bit is impregnated with small industrial diamond fragments. They are especially recommended for very hard, broken formations, which might result in "shelling" of diamonds from a set bit. Sand-blasting is sometimes required to expose new cutting points on these bits. They cannot be reset and have no salvage value. They are used until completely worn out and then discarded.

Boring in loose, unconsolidated materials will seriously damage diamond bits. Where unconsolidated materials must be penetrated to reach rock, casing should be used and the hole thoroughly cleaned before boring with a diamond bit. Flush-coupled casing is usually used for this purpose.

A split-ring core catcher is usually employed to seize the core when the barrel is lifted; after the core is broken off the catcher holds it in the barrel.

The inner barrel may or may not have vents to permit escape of the water displaced by the core. Omission of the vents theoretically reduces friction because water in the inner barrel above the core must be forced out between the core and the barrel, lubricating it. On the other hand, the escaping fluid may cause erosion of soft rock cores if the vents are omitted.

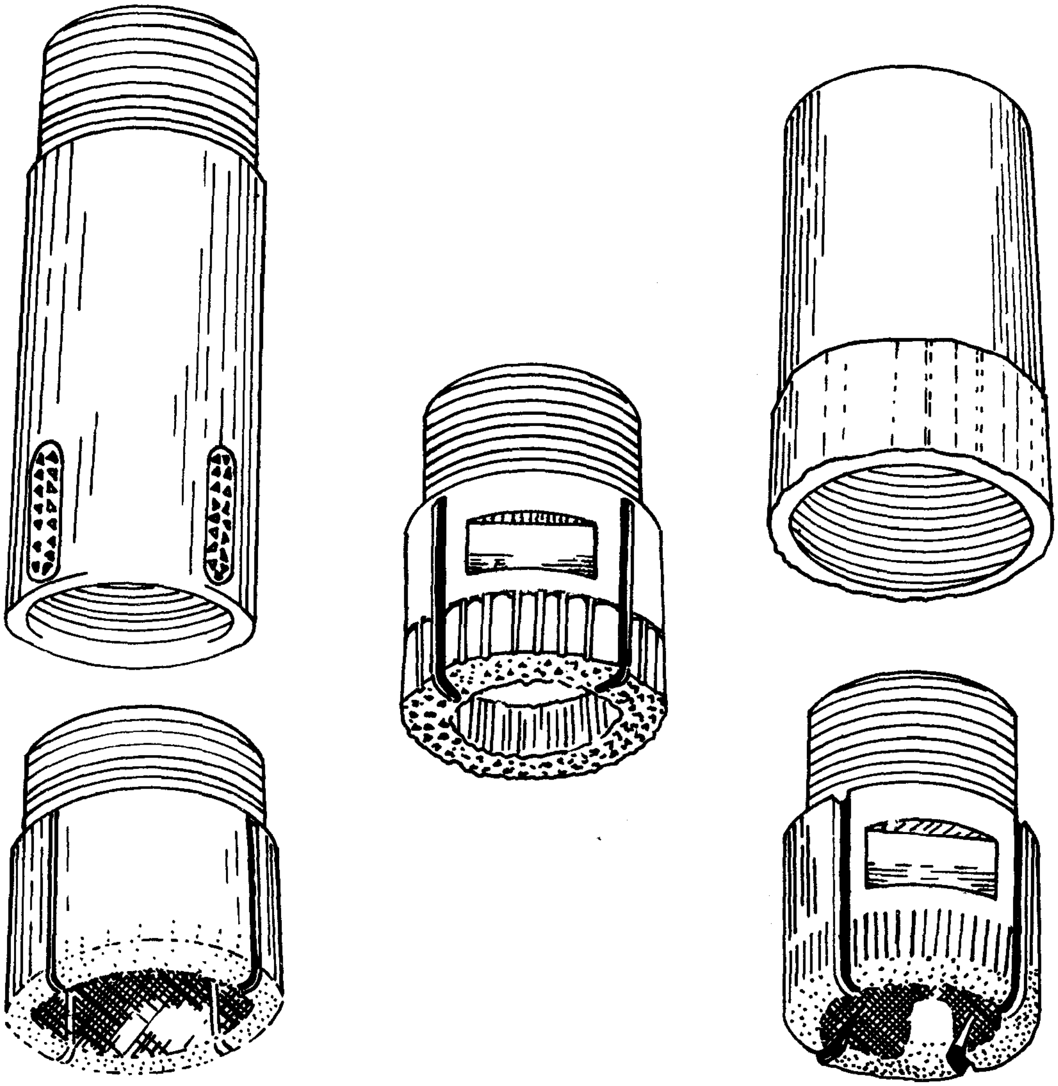


Figure 2-19 Diamond Bits and Reaming Shells

Rock core bit speed--Excessive bit speed will result in chattering and rapid wear of the bit and will break the core. A low bit speed results in a slow rate of progress and higher wear on diamonds. As the equipment becomes worn and the drill rods poorly aligned, it may be necessary to decrease the bit speed in order to avoid excessive vibration, whip, and chattering of the bit with consequent danger of breaking the core and damagine the bit. Higher speeds should be used in hard rock and lower in soft or broken rock. Diamond bit drilling speeds vary from 300 to 1500 rpm, while those for metal bits vary from 100 to 500 rpm.

Rock core bit pressure--The rate at which the coring bit is advanced depends upon the amount of bit pressure used. This pressure must be carefully adjusted to the character of the rock, the type of bit, and the bit speed. Excessive bit pressures, expecially in soft rock, will cause the bit to plug and may possibly shear the core from its base. The bit pressure is controlled by a hydraulic feed on the drilling machine. For shallow drilling, the weight of the drilling column will never exceed the optimum bit pressure except in very soft rock.

In hard rock a high feed pressure on diamond bits not only increases the rate of advance but also keeps the bit sharp and free cutting. A low feed pressure in the same rock tends to polish the diamonds. In softer rock the best results may be obtained with relatively low feed pressures.

Drilling fluids--Clear water is generally preferred to drilling mud in rock coring. Water requires smaller fluid passages and pump pressures, and the rock cuttings are generally fine and easily carried to the surface. In some cases air circulation is used with coring.

Where water is used, the flow of the return water should be regulated so that the cuttings are just carried out of the hole. If too much is used, the velocity across the bit face is increased which results in bit erosion. The metal holding the diamonds in a bit may be scoured away, leaving the diamonds exposed and easily pulled out. The flow should be increased when softer rock is being cored and larger sized cuttings are formed. However, it must not be great enough to wash away the core.

If water pressure begins to build up, there is generally some restriction at the bit face or in the core barrel. "Plugging" may occur where the rock is fractured or contains many seams. In this event a piece of rock wedges in the bottom of the core barrel, but also restricts water flow. The barrel may sometimes be cleared by lifting off the bottom a few inches and letting the hole wash. Sometimes it is best, if plugging is a problem, to drill through seams of broken rock with a roller bit. This method has the disadvantage, however, that no core is obtained.

If a diamond bit is run without sufficient cooling water (or air circulation), it will rapidly burn and stick fast and may be ruined.

A serious condition frequently encountered is the loss or "running off" of return water into cavities in the rock, causing what is known as a "blind hole." This condition can often be corrected by adding leaves, grass, or cotton hulls to the water. Such materials will often seal seams and cavities in the sides of the hole.

Hole cleaning--The hole should always be washed before starting to drill, as well as before pulling out the rods and tools. It should be kept in mind that at the end of a run there is a column of water extending the full length of the hole carrying the cuttings in suspension. If the pump is stopped immediately, these cuttings will settle to the bottom and when the bit is lowered it will rest upon a thick layer of mud instead of clean rock. The pump should be kept running until the return water is clear. When drilling through soft rock where there is a chance of washing the core away, the core barrel should be raised at least six inches before washing.

Core recovery--Percentage core recovery is an important factor in rock coring operations. The rock below the core barrel and in the lower part of the core is subject to torsion and vertical forces. The core is cut to a slightly smaller diameter than the inside diameter of the core barrel inner tube and, excepting cores of certain soft and swelling rocks, there is very little inside wall friction as long as the core is unbroken. However, inside friction develops when the core is broken and rock fragments become wedged between the core and inner barrel. A greater part of the feed pressure may then be transmitted to the core and to the rock directly below the core. The result is that weak sections of the rock, and possible all of it, is broken up and removed by the circulating water instead of entering the core barrel.

Since the torsional moment of resistance of the core increases with the cube of its diameter, an increase in diameter is very effective in reducing breakage and increasing the recovery ratio and the length of core obtainable. Normally the "NX" barrel (2-1/8-inch diameter core) is the smallest core barrel which should be used, mainly because of core recovery problems.

Other factors may also influence core recovery. Faulty core catchers may cause the loss of much core. Excessive water use may wash soft materials away. Warped drill rods or worn guides may result in undersize or broken and ground up core. The proper selection of bits, although primarily influencing the rate of drilling, has some application to core recovery, particularly in soft formations. For example, a steel bit is usually more effective in shale than a diamond bit, both in rate of drilling and amount of recovery. Diamond bits generally have better recovery ratios than steel bits in harder rock.

Obviously, no core can be recovered when openings such as caverns, solution channels, or large open joints are encountered. The presence of such cavities can often be recognized by the drilling tools dropping several inches, suddenly, accompanied by a loss of water circulation.

In removing the core from the barrel it may be necessary to tap the barrel lightly with a hammer. The core should be laid out exactly as it comes out of the barrel, and allowances made for seams or fissures run through. The core barrel should be thoroughly washed and the joints lubricated before reassembling.

General considerations for rock coring--The following general considerations should be observed in rock coring work:

1. Always lower rods and tools carefully. Dropping an expensive diamond bit on the bottom of the hole can cause serious damage.

2. Don't let the drill bit bounce or vibrate on the formation.

3. Don't start the bit while it is resting on rock. Spin it into the formation slowly and cautiously at first. Increase the feed after penetrating four to six feet. The top rock is usually weathered, fractured, and seamy. Remember the old axiom among drillers that "more damage is done to the bit in the first five feet than in the next hundred." Also, the "solid rock" being drilled could be a boulder or projecting ledge, after which the bit could be ruined running through gravel and cobbles.

4. Don't slide a diamond bit over old core - spin over it. This will result in less diamond loss. A roller bit should be used if much core or caved material is left in the drill hole.

5. Don't throw a diamond bit into the tool box. Wash it off at the end of a run, disconnect it from the barrel, and put it away carefully. Never use a wrench on the diamond area. It is a diamond tool - treat it as such.

6. Don't force a diamond bit. The diamonds are set for maximum performance. If penetration rate in a uniform formation decreases, with bit speed and feed rate remaining the same, take off the bit. More damage is done to diamond bits through pressing to obtain another barrel of core than in any other way. If the bit is continued in service too long, the exposed diamonds are pulled out, and the loose stones riding around the bottom of the hole can quickly destroy the entire bit.

7. Check the rods and joints for leaks. Split or improperly connected rods can seriously reduce the circulation and cause overheating of bits.

8. Check the core barrels to make certain they are straight. Pay particular attention to the core barrel head.

9. Feed the drill with a steady pressure. Increasing or decreasing pressure and bit speed in a given formation normally will not increase rate of penetration but it will increase operating costs.

10. Keep an accurate record of the lengths of drill rods and tools in use. Trusting to memory can be expensive. In trying to remember odd lengths of drill rod, many a driller has become confused and dropped a string of tools 10 to 15 feet because he thought they were already on the bottom.

Tools for Advancing Bore Holes

Auger Bits

Many types of auger bits are available on the market. Helical or worm-type bits, sometimes called flight augers, are the most common. These are usually made in sections which may be added just as drill pipe is added. The augered material is brought to the surface by the helical action of the auger. A flight auger is useful for rapid advancement of holes. Since continuous flight augers mix materials throughout the hole, it is impossible to obtain a sample representative of one horizon. Where it is necessary to obtain a sample for logging or other purposes, augering should be stopped and a split-tube or other sampler substituted.

Other types of augers may have open or semi-closed sides. These have the advantage of less mixing of material than helical augers. The SCS has developed a set of auger bits, termed bucket auger bits, which are especially adapted for use with power augers for logging homogeneous materials and obtaining representative disturbed samples. These bits are shown in Figure 2-20. The open slat-type is adapted for use in cohesive materials, the closed cylindrical type in non-cohesive materials, and the semi-closed cylindrical type in intermediate materials.

The diameter of auger bit to use depends upon the purpose of the bore hole. The minimum diameter should not be less than three inches. Larger bits are required for relief wells. Auger bits may be used with either a rotary drilling rig or power auger. A different tool joint at the top of the auger bit, or a sub, may be required for use on different rigs.

Barrel Auger

The so-called "dry barrel sampler" (Figure 2-21) may be used with a core drill as a substitute for the auger bit. It is a completely closed cylindrical auger with no cutouts on the sides of the barrel. The cutting bit should have a slightly smaller inside diameter than the inside diameter of the barrel, to assist in removing the sample.

The sampler can be used as a substitute for an auger bit in cohesive soils. Water circulation is required for its use. The barrel is pushed into the soil with a rotary motion as with an auger bit. After the barrel has been removed from the hole, the sample is forced out and onto the sample catch pan by water pressure. This method of boring is much faster than dry augering with bucket augers in most soils, since it eliminates the time-consuming removal of materials from the auger bit by hand. As may be seen in Figure 2-21, the barrel is of very simple construction and can be made in any machine shop from casing, a modified casing shoe, and and adapter.

Chopping, Fishtail, and Jetting Bits

Chopping, fishtail, and jetting bits are used to detach and clean out material accumulated inside the drive pipe or casing. Water is pumped through the string of drill rods and discharged through ports at the face of the bit. Bits have different types of chopping edges designed for cutting into different types of materials. Hard steel alloys are commonly used to prevent excessive wear. Chopping, fishtail, and jetting bits come in a variety of shapes and sizes, the shape depending upon the type of material and size on the diameter of casing used. Normally a chisel or wedge-shaped bit is satisfactory for cohesive materials. Cross-chopping bits are designed for use in coarse gravel and boulders. Fishtail bits (Figure 2-22) are used for soft rock. A 2-5/8 bit is generally used in 3-inch casing. Large fishtail bits, 20 inches in diameter, often prove useful for installing relief wells.

Roller Bits

Roller bits usually have three sets of rollers with meshing, self-cleaning, hard-surfaced teeth. They are used for advancing holes in overburden and rock when no cores are required. This type of rock bit is commonly used in conjunction with augering to cut through rock after which augering is continued with a slightly smaller bit. The teeth are flushed by drilling fluid flowing out of vents in the base of the bit, and the cuttings are carried up through the hole.

Roller bits are manufactured in various sizes ranging from 2-3/8 inches to more than a foot. A tri-cone roller bit is shown in Figure 2-22

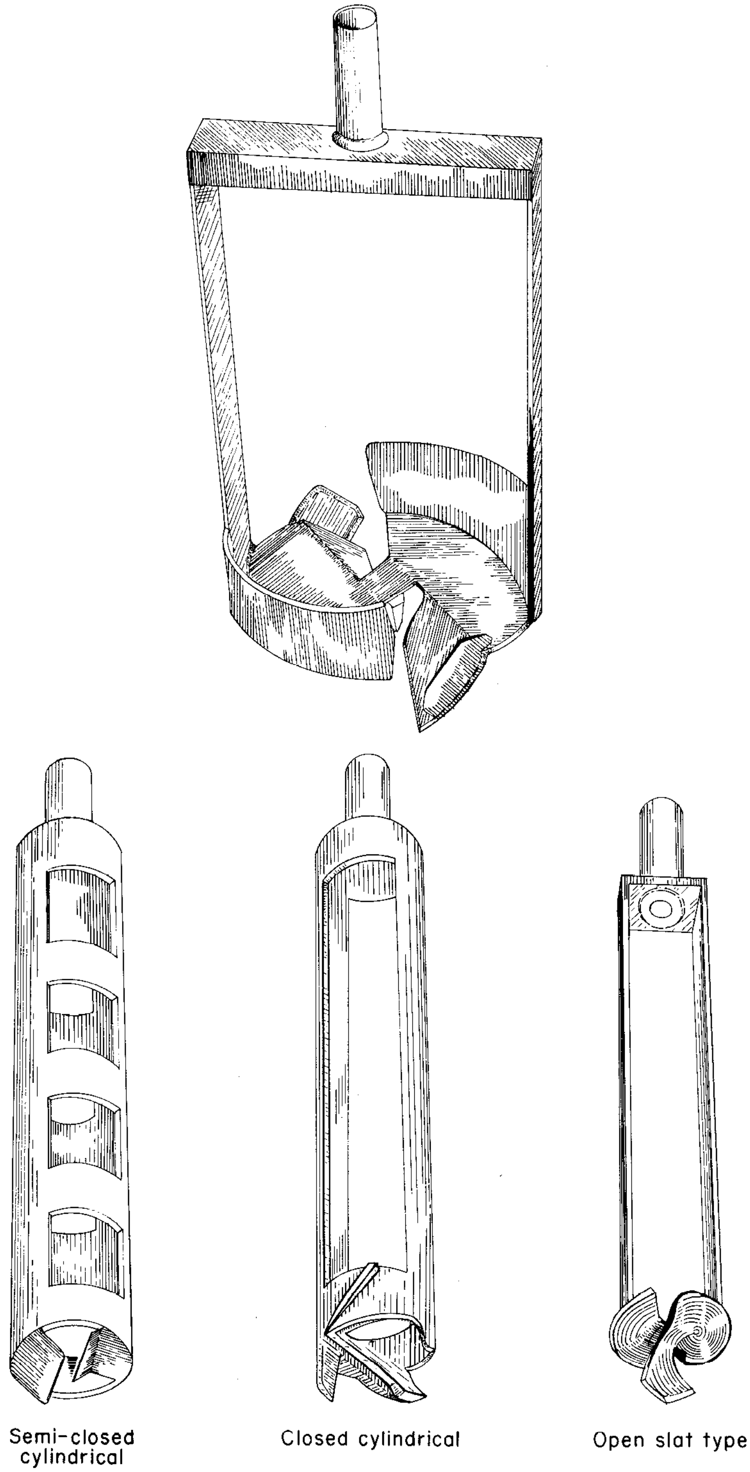


Figure 2-20 Various Types of Bucket-Auger Bits

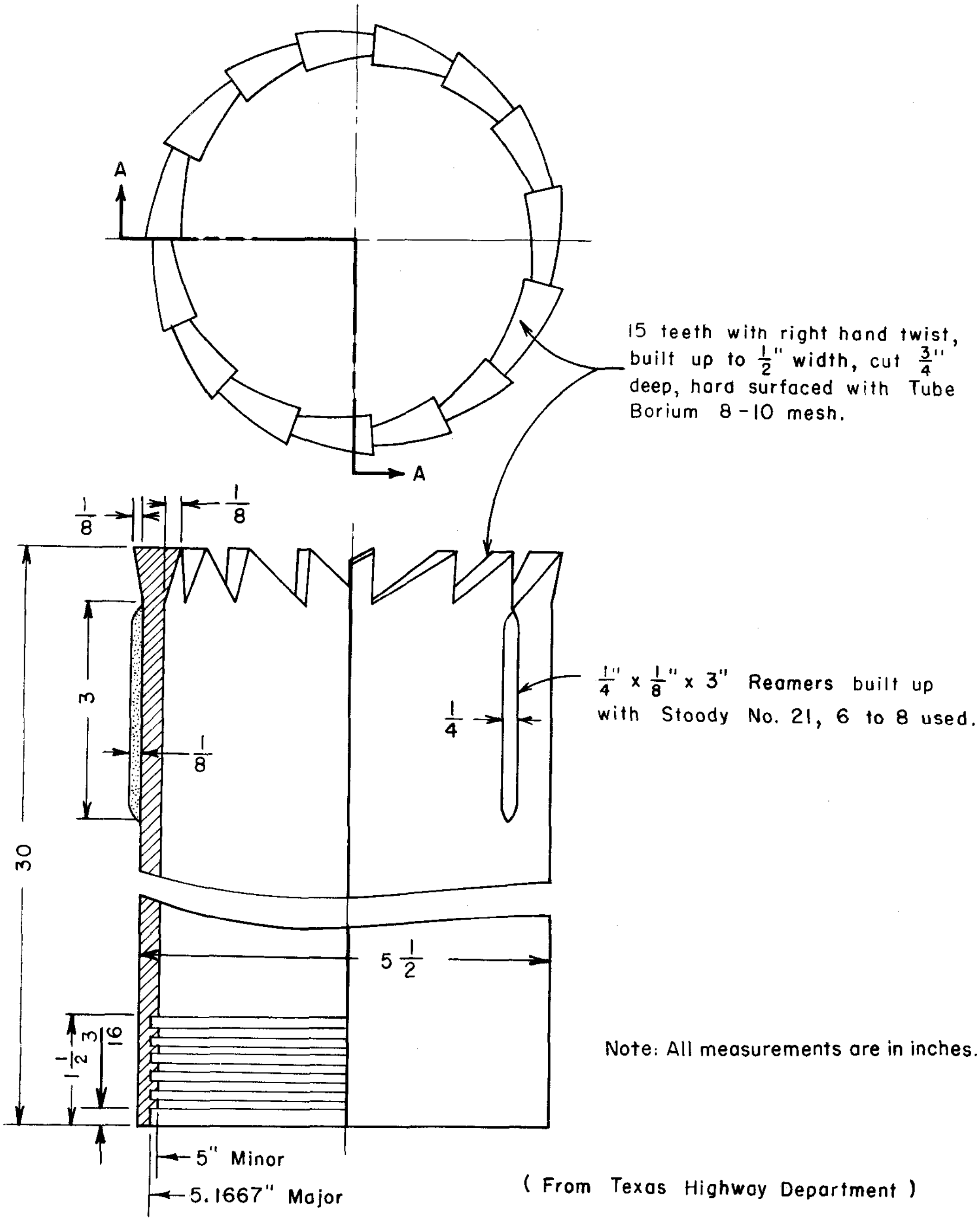


Figure 2-21 Dry Barrel Samples

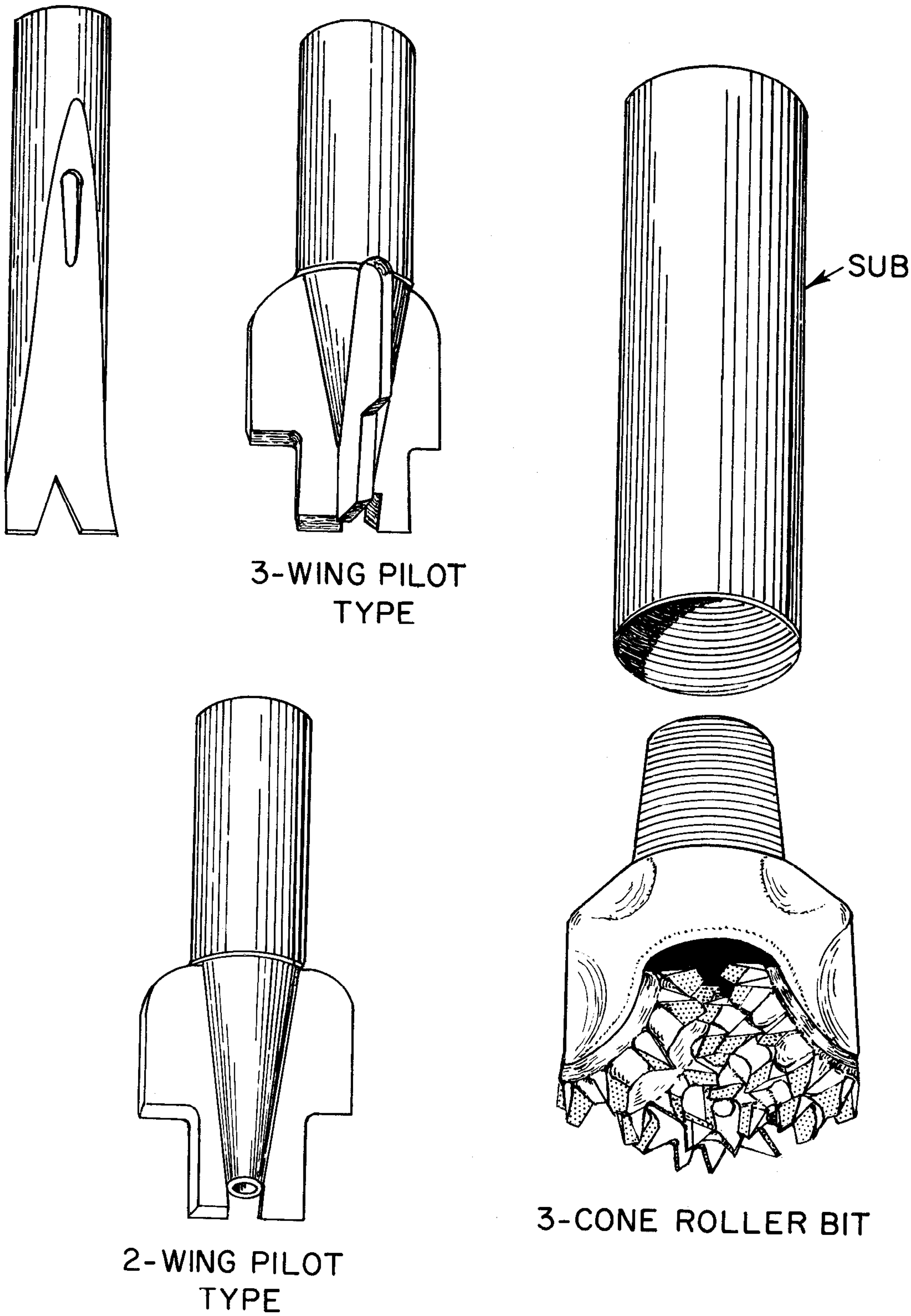


Figure 2-22 Various Types of Fishtail and Roller Bits

Other Drilling Equipment

General

In addition to the cutting and sampling tools outlined on the foregoing pages, certain additional equipment is needed to carry out boring and sampling operations. Needed and optional miscellaneous equipment is described on the following pages.

Drive Hammers

Drive hammers (Figure 2-23) are required for driving casing and for conducting standard penetration tests. A 140-pound hammer is required for the standard penetration test and heavier hammers are used for driving and removing casing. They may be operated manually or automatically. All drill rigs should be equipped, at least, with the 140-pound hammer. Where it is anticipated that considerable driving of casing might be necessary, an additional heavier drive hammer will result in more efficient operations.

Drill Rod and Couplings

Table 2-10 lists the various sizes of drill rods and couplings which are normally recommended for SCS work.

Many types of tool joints and drill rod couplings are available. Some types, such as those with tapered thread joints, are more subject to wear and to splitting of the female joint or box than others. The non-tapered flush joint, three threads per inch, is satisfactory.

Drill rod is normally manufactured with a box on each end. It is good practice to use a drill rod adapter or sub on each end. The female connection is made by means of a pin to box sub screwed into one end of the pipe. The male connection is made by means of a pin to pin sub screwed into the other end. When the subs become worn or damaged, they can be replaced at less cost than replacing the entire section of drill rod.

Drill rod not exceeding ten-foot length (ten feet, six inches with subs on both ends) is best adapted for site investigations. Twenty-foot lengths of drill rod are cumbersome to handle and transport. It is desirable for the mast of a rotary drill to be of sufficient height to handle at least two ten-foot lengths with subs (21 feet). This greatly expedites placing and removing tools from deep bore holes. The number of sections needed for a particular drilling rig will depend on the maximum number of feet which might be bored with the rig (seldom more than 100 feet), plus several spare rods for replacement in event of damage.

Solid drill rods are used with power augers where water circulation is not used. Flush joint drill rod of standard "AW" size, 1-3/4 inch outside diameter, or "BW" size is satisfactory for most power auger operations.

Since the joints need not be watertight, a simple joint such as a square pin and box, connected by a drive pin, is satisfactory.

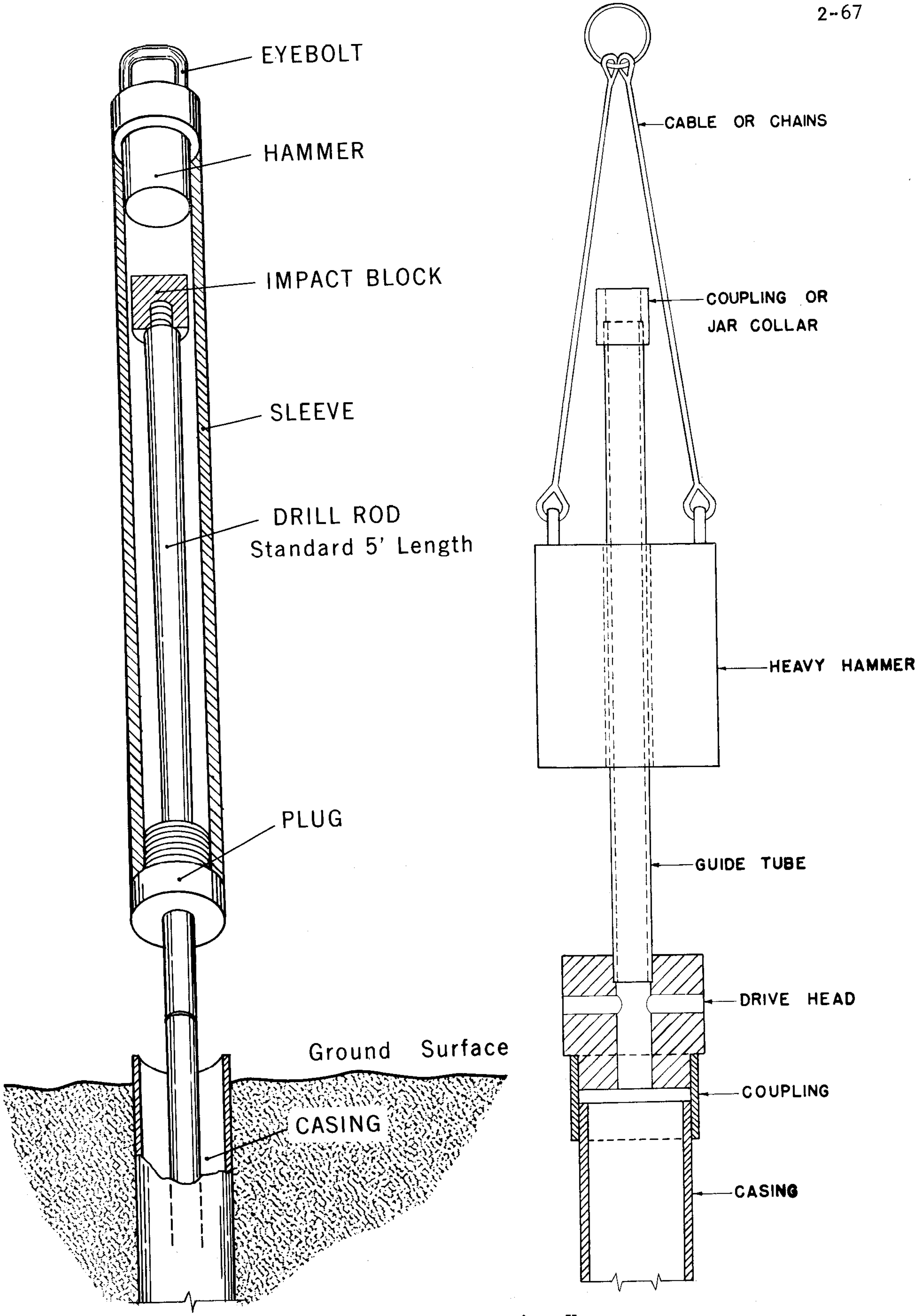


Figure 2-23 Safety and Casing Drive Hammers

Normally three 10-foot, two 5-foot, and two 2-foot lengths of drill rod will be ample for augering.

Clean-Out Tools
Clean-out tools are necessary for cleaning out bore holes preparatory to sampling. Materials which contaminate the sample or which may damage the sample must be removed. The type of tool and method required depends upon the nature of material to be removed. Certain types of cutting tools used for advancing holes such as barrel and bucket augers, leave relatively clean dry holes. Other types may leave gravel, slurry, water, drilling mud and other material in the hole. When the drilling hole contains slurry and drilling mud only, these materials may be removed by washing and flushing. Other types of materials require special tools. Some of these are described as follows:

Hole bailer - A hole bailer is useful for removing water and fine slurry. Its principal use is to remove water in the measurements of groundwater level. The outside diameter of the bailer should be one inch smaller than the hole diameter and preferably five feet long. It should have a dart bottom valve. A bailer of this type is shown in Figure 2-24.

Clean-out tools - Hole-cleaning tools perform the function of removing loose soil and rock particles from the bottom of a hole before samples are taken. Various types of cleaning tools have been designed to operate in various soil conditions. These tools include jetting wash pipe with scrapers, clean out jet augers, and sludge barrels. Some of these are illustrated in Figure 2-24.

Sample Catch Pan
A sample catch pan is needed when augering with either a rotary drilling rig or power auger. When the auger bit is raised, the pan is placed under it and the soil knocked into it. The material from the pan is then dumped in piles representing 1.0 to 2.0 foot increments for visual inspection. Normally this pan should measure about two feet by two feet. It may be fabricated locally.

Barrel Rack
A barrel rack will also be helpful to remove cores from double-tube soil and rock core barrels. A typical rack of this type is shown in Figure 2-25. It should be designed to fit the sizes of barrels being used. It is not available on the market and must be specially fabricated.

Slush Pits
Portable, or tank-type, slush pits are sold by some drilling equipment companies for use with rotary drill rigs. They may be needed where hard rock or gravel beds prohibit digging of adequate slush pits. Each time the drilling rig is moved, the mud and water must be removed from the tank to make it light

enough to move. When possible, it is easier and faster to dig a small pit or sump for the drilling fluid at each hole. This is particularly true for shallow drilling and frequent moving from hole to hole.

Miscellaneous Equipment

There are many additional tools and pieces of equipment which facilitate drilling operations. Some are optional while others are necessary to carry out certain cutting and sampling procedures. The uses of some tools such as boulder busters, fishing and recovery tools, water swivels, foot clamps, and pulling plates are quite obvious and need no further description. (See Figure 2-26.) Some additional equipment which may be useful in expediting site investigations is described briefly in the following section.

Water And Tool Trucks

If the source of water is remote from the site, considerable drilling time may be lost by continual interruptions for replacement of water. Where it is anticipated that such conditions may be encountered repeatedly, it may be advantageous to have a separate water and tool truck.

Mobile Trailer

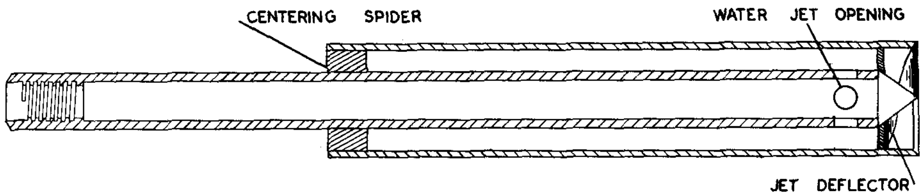
Drilling parties may be equipped with a mobile trailer or field office. These trailers should be equipped with desk, filing cabinet, butane heating stove, butane hot plate for melting wax and drying samples, and cabinets in which diamond bits and other equipment may be kept.

Miscellaneous Items

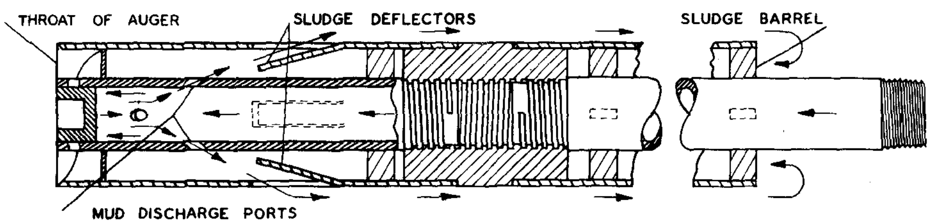
Other items which may be useful include testing kits for gypsum, calcium carbonate, montmorillonite, or other minerals, a hand level, sieves, a Brunton compass, and geologic maps and literature on the area. A dumpy level, level rod, and aneroid barometer may also be useful. A mirror is useful in reflecting sunlight into drill holes. Oxyacetylene welding equipment is very useful for periodic rebuilding of bits with the borium or other hard alloys, and for general field repairs to the drilling equipment and vehicles.

Drill Rigs

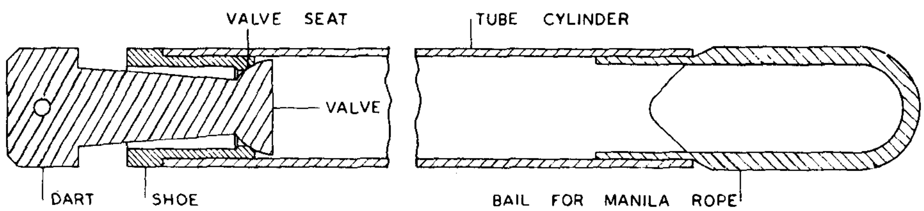
The term "drill rig" implies all of the equipment necessary to operate cutting and sampling tools. In general, it embodies such items as the power unit, derrick, drillhead, draw works, transmission, controls, and other appurtenances. Drill rigs may be truck, trailer, or skid-mounted. (See Figure 2-27.



STANDARD CLEANOUT AUGER



CLEANOUT AUGER
WITH SLUDGE BARREL



DART VALVE BAILER

Figure 2-24 Hole Bailer and Clean-Out Augers

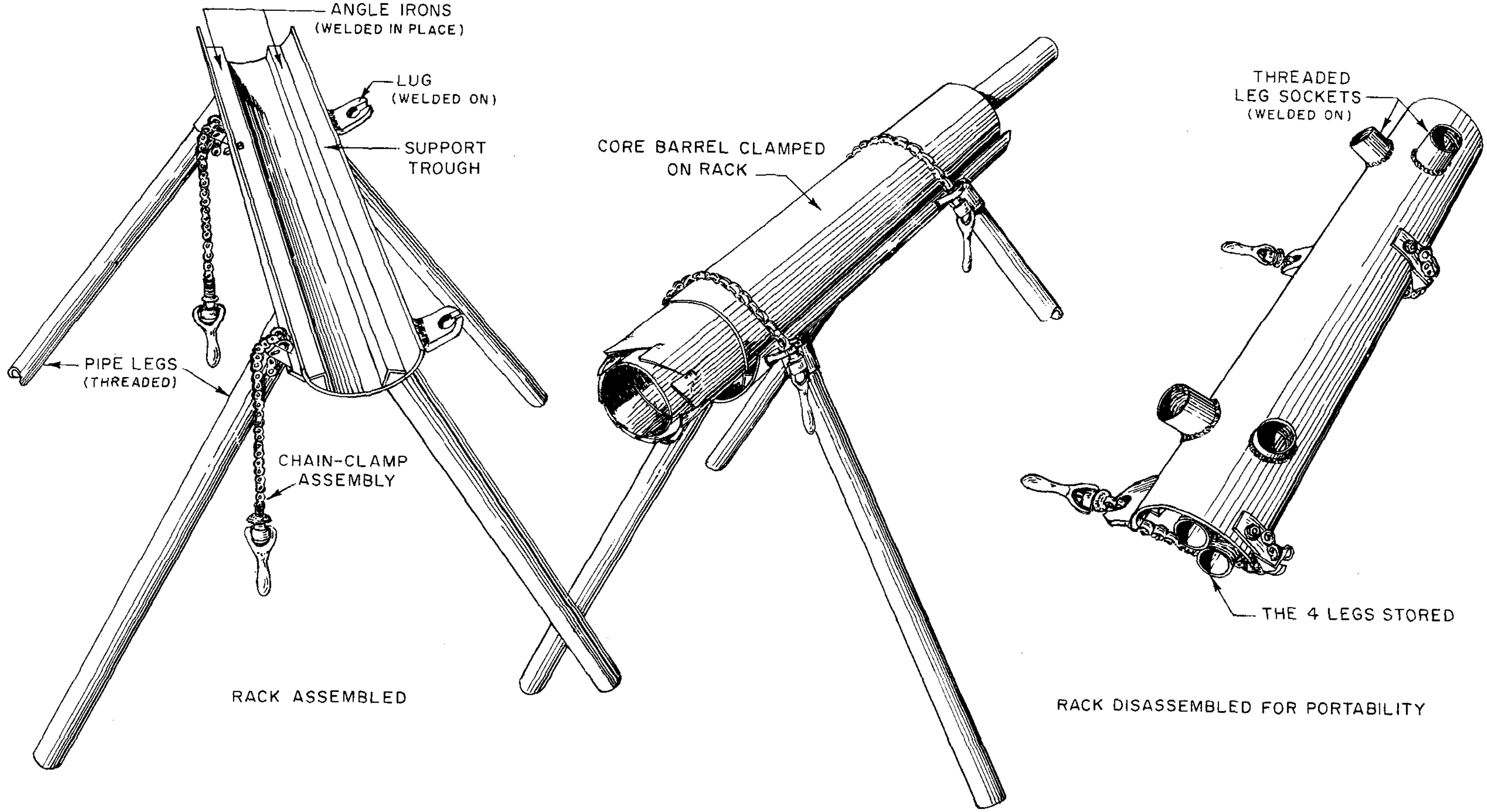
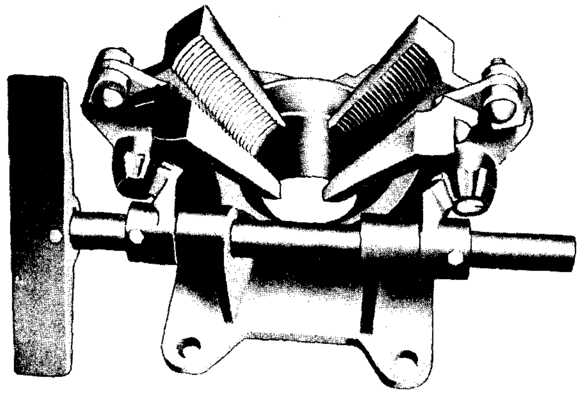
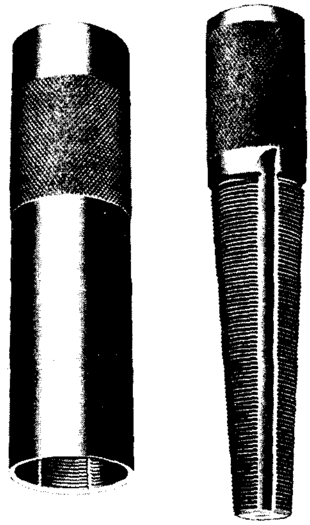


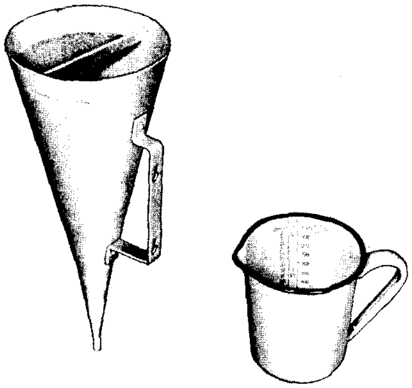
Figure 2-25 Barrel Rack with Barrel in Place



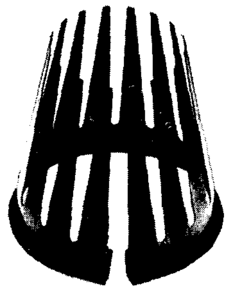
Safety foot clamp



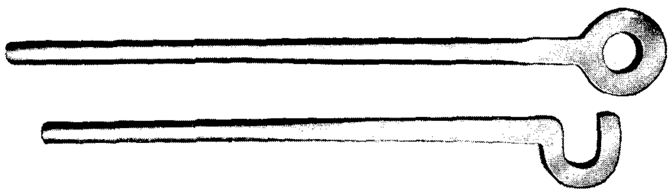
Drill rod taps



Marsh funnel and
graduated cup



Core catcher
(spring type)



Holding irons

Figure 2-26 Miscellaneous Equipment

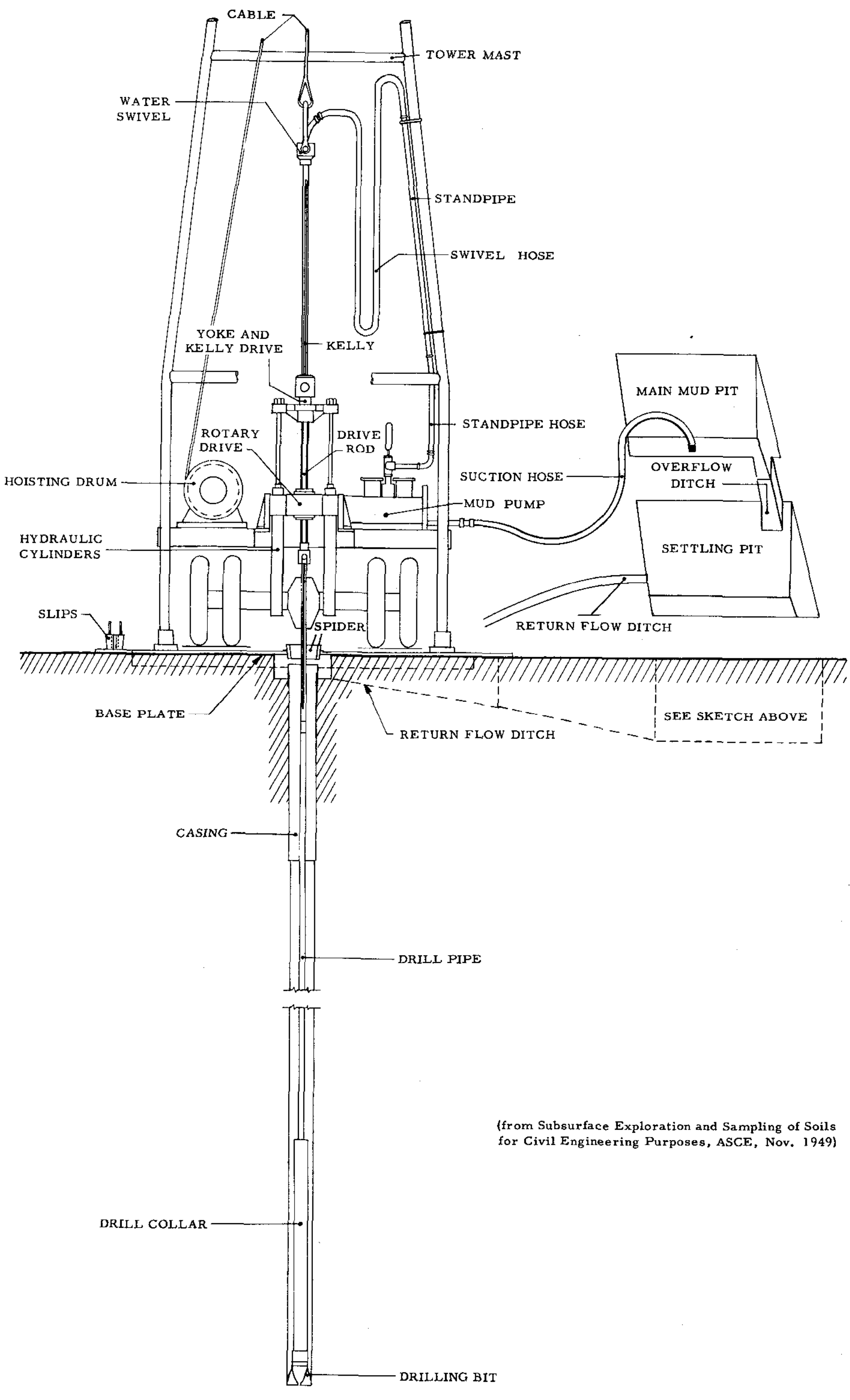


Figure 2-27 Rotary Drilling Rig

There are many types of drill rigs available on the open market. Each is capable of performing certain kinds of work. Most can be augmented in respect to component parts and mounting. The selection of the proper drill rig to carry out a particular work load depends on numerous conditions. These include the anticipated work load in respect to size and purpose of proposed structures; the nature of site conditions in respect to character of materials to be bored, depth of boring, and sample requirements; terrain; and other conditions.

Guidance in the selection of adequate drill rigs to meet conditions to be encountered in the work load of a particular state may be obtained from the E&WP unit serving that state.

Stabilizing Bore Holes

Casing

Temporary casing or lining of the bore hole with steel pipe is the most positive method of stabilizing a bore hole. It is normally required for certain methods of advancing holes such as percussion drilling.

Many types of standard and special pipe are used as casing. Recessed outside couplings provide the strongest joint and are commonly used in soils exploration. An open joint is used under normal conditions, but a butt joint is often preferred when the casing is to be driven through hard ground or ahead of the boring. Repeated use will damage the threads of open joints and cause beading and upsetting of butt joints. Flush jointed casing has a smaller resistance to driving and withdrawal than casing with outside coupling.

The lower end of the casing is generally protected by a casing shoe of hardened steel, with an inside bevel so that displaced materials will be forced into the pipe.

Because of the expense and time consumed in casing rotary core drill holes, it normally is not used where holes can be stabilized with drilling mud. Casing is required for the installation of relief wells. In this respect the purpose is to hold back wet, loose formations while the filter pack material is being placed around the well screen.

Drilling Fluids

An uncased shallow bore hole of the type usually drilled by rotary core drilling methods can ordinarily be stabilized with a properly proportioned drilling fluid or "mud" (Table 2-11). Drilling muds consist of highly colloidal gel-forming clays. Native clays may also be added to the drilling fluid. The drilling fluid forms a relatively impervious lining or "mud-cake" on the side walls of the bore hole. Weighting materials such as ground barite may be added to the drilling fluid to increase its specific gravity and prevent caving of the hole in troublesome soils or when the fluid must carry very coarse-grained materials in suspension. Two slush pits should usually be dug downslope from the drill hole, with a small channel connecting them and the drill hole. The drilling fluid will then flow from the hole to the first pit, where the coarse material will settle out, and then to the second pit, where the mud can be picked up for recirculation (see Figure 2-27). Sand should be removed from the pits as it accumulates. If this is not done, the pump and the sampler may become clogged with sand. If coarse material is not present, one slush pit may suffice.

When using drilling fluids, the pump pressure and discharge should be hand controlled for soils and soft erodible rock so that the rate of circulation of drilling fluid can be controlled independently of bit speed. If the rate of circulation is too slow, or the bit pressure too great, the bit and fluid passages will plug. If the flow is too great (this is often the case), erosion of the core and soil below the bit will result. In the latter case, the drilling fluid may be forced to seek a path inside the cutting shoe, alongside the soil core, and through the vents, thereby eroding or removing part of the core. Generally, the pump pressure should be the minimum amount necessary to circulate the mud freely and carry the cuttings from the hole.

Pumps should have a control for regulating water pressure. If the pump has a separate power plant, pump pressure can be adjusted independently of bit speed.

Rigs which have a common power plant to turn the bit and run the pump, should be equipped to bypass part of the fluid, and reduce flow to the sampler.

Table 2-11 Approximate Proportions of Mud Mixtures 1/

Purpose of drilling mud	Approximate proportions of material per barrel of water 2/	Viscosity 3/	Descriptive consistency
Assisting cutting operations by the sampler	10 to 30 pounds of bentonite	Variable as needed	Variable as needed
For lifting cuttings from hole	10 to 15 pounds of bentonite for fine-grained soils	Slightly higher than water	Thin cream
	30 pounds of bentonite for coarse-grained material	About 1.3 times the viscosity of water	Very thick cream
For supporting the drill hole	30 pounds of bentonite and 5 pounds of barite	About 1.3 times the viscosity of water	Very thick cream
For assisting to hold the sample in the sampler	10 to 30 pounds of bentonite and 0 to 10 pounds of barite	Slightly higher than water to 1.3 times the viscosity of water	Thin cream to very thick cream

1/ (U.S.B.R. Earth Manual, Tentative Edition with Revisions, 1951, 1958).

2/ One barrel equal to 50 gallons.

3/ Viscosity is measured by a Marsh funnel (see Figure 2-26) which is calibrated with water at 72° F. The time required for a given amount of water to flow through the funnel is considered as 1.0. The value listed above is the relative time for the same amount of mud mixture to flow through the funnel.