

Chapter 5 Equipment for Undisturbed Soil Sampling in Borings

5-1. Sampler Types

A variety of samplers are available for obtaining undisturbed soil samples. Basically all are variations of the push-type thin-walled tube samplers or rotary core barrel samplers. Push-type tube samplers may be used to obtain samples of soft-to-medium clays and fine sands. These samplers should not be driven by hammering to obtain undisturbed samples. A rotary core-barrel type sampler should be used to obtain undisturbed samples of soils too hard to permit smooth penetration of the push-type sampling tube or soils which contain gravel that may damage the tube as well as disturb the soil sample. Procedures for undisturbed soil sampling in boreholes are discussed in Chapter 6.

a. Push-tube samplers. Push-tube samplers are merely pushed into the undisturbed soil in one continuous, uniform motion without rotation. These samplers may be used for obtaining undisturbed samples of most soils which are not too hard to penetrate or contain gravels. When a properly beveled cutting edge on the sampling tube is used, the soil which is displaced by the sampling tube is compacted or compressed into the surrounding soils.

Push-tube samplers can be subdivided into two broad groups: open samplers and piston samplers. Open samplers consist of an open tube which is attached to a vented sampler head. The open tube admits soil as soon as the tube is pushed into the soil. The sampler head may be equipped with a ball check valve which holds a partial vacuum above the sample that aids in sample recovery and prevents the entrance of drilling fluid during sample withdrawal. Piston samplers have a movable piston located within the sampler tube. The piston keeps drilling fluid and soil cuttings out of the sampling tube as the sampler is lowered into the borehole. It also helps to retain the sample in the sampling tube by holding a partial vacuum above the sample that aids in sample recovery.

As compared to piston samplers, open samplers are cheap, rugged, and simple to operate. The principal disadvantages include the potential for obtaining nonrepresentative or disturbed samples due to improper cleaning of the borehole or collapse of the sides of the borehole and loss of the sample during recovery.

(1) *Open samplers.* The sampling tubes for open samplers may be either thick-walled or thin-walled. However, thick-walled tubes generally exceed the area ratio of 10 to 20 percent which is specified in paragraph 2-3a. Therefore, the quality of undisturbed samples which are obtained with the thick-walled sampling tubes is suspect. Hence, only thin-walled samplers are discussed in this section.

The thin-walled open sampler consists of some type of seamless steel tube which is affixed to a sampler head assembly with screws as suggested by ASTM D 1587-83 (ASTM 1993). The sampler head assembly is equipped with vents which permit the escape of air or drilling fluid from the tube as the sampler is advanced. The vents should be equipped with a ball check valve to prevent entrance of drilling fluid during withdrawal and to create a partial vacuum above the sample which aids in sample recovery. Sampler heads for 7.5- or 12.5-cm- (3- or 5-in.-) diam tubes are available. The sampler head assembly for the 7.5-cm-(3-in.-) diam tubes can also be modified to fit the 12.5-cm- (5-in.-) diam tubes by use of an adapter ring.

The sampling tubes may be cold-drawn seamless or welded and drawn over a mandrel steel tubing. The tubes may be of variable length but are commonly furnished in 0.91-m (36-in.) lengths. The tubes are normally 7.5- or 12.5-cm OD and are sharpened on one end. Because the quality of the sample depends partially on the wall thickness of the tube, the tube with the thinnest wall possible will generally provide better samples. Typically, the wall thickness should be 14 gauge (0.211 cm or 0.083 in.) for the 7.5-cm-diam tubes and 11 gauge (0.305 cm or 0.120 in.) for the 12.5-cm-diam tubes. To minimize the potential for damage of the thin-walled tubes by buckling or by blunting or tearing of the cutting edge and disturbance to the sample, the sample tube is pushed into the undisturbed soil in one continuous, uniform motion without rotation.

One end of the tube should be beveled or tapered to form a sharpened cutting surface (paragraph 2-3). The taper angle on the outside surface should be about 10 to 15 deg. The ID of the cutting edge should be equal to or slightly less than the ID of the tube. This inside clearance, i.e., inside clearance ratio, is necessary to minimize the drag of the soil sample on the inside of the tube and still retain the sample in the tube. Cohesive soils and slightly expansive soils require larger inside clearance ratios, while soils with little or no cohesion require little or no inside clearance ratios. Typically, sampling tubes with inside

clearance ratios, or swage, of 0 to 1.5 percent of the tube ID are commonly used. (See paragraph 2-4.)

Thin-walled open samplers can be used to obtain samples of medium soft to medium stiff cohesive soils. Materials which cannot be sampled with this device include soils which are hard, cemented, or too gravelly for sampler penetration, or soils which are so soft or wet that the sample compresses or will not stay in the tube. However, open tube samplers are not recommended for obtaining undisturbed samples from boreholes. The quality of the sample may be suspect because of the inherent design of the sampler. During sampling operations, the pressure above the sample may increase because of drilling fluid in the barrel of the sampler or overdriving of the sampler. During withdrawal, vibrations of the sampler and/or the vacuum created under the sample may result in loss of the sample. Figure 5-1 is a schematic drawing of an open sampler. A diagram of sampling operations using the open tube sampler is presented in Figure 5-2.

(2) *Piston samplers.* Pistons were incorporated into the design of samplers to prevent soil from entering the sampling tube before the sampling depth is attained and to reduce sample loss during withdrawal of the sampling tube and sample. The vacuum which is formed by the movement of the piston away from the end of the sampling tube during sampling operations tends to increase the length of the sample recovered. The advantages of piston samplers include: debris is prevented from entering the sampling tube prior to sampling; excess soil is prevented from entering the sampling tube during sampling; and sample recovery is increased. Hvorslev (1949) stated that the piston sampler "has more advantages and comes closer to fulfilling the requirements for an all-purpose sampler than any other type." The principal disadvantages of the piston samplers are increased complexity and cost.

Three general types of piston samplers include free- or semifixed-piston samplers, fixed-piston samplers, and retractable-piston samplers. A brief synopsis of each type of piston sampler follows.

Free- or semifixed-piston samplers have an internal piston which may be clamped during withdrawal of the sampling tube. During the actual sampling operations, the piston is free to move with respect to the ground level and sample tube.

To obtain a sample with a fixed-piston sampler, the sampling apparatus is lowered to the desired level of sampling. The piston is then freed from the sampler

head, although it remains fixed relative to the ground surface. The sample is obtained, and the piston is again clamped relative to the sampler head prior to extracting the sample and sampling tube from the borehole.

The retractable-piston sampler uses the piston to prevent unwanted debris from entering the sample tube while lowering the sampler to the desired depth. Prior to the sampling operation, the piston is retracted to the top of the tube. However, this operation may cause soil to flow upward into the tube. Consequently, the retractable piston sampler is not recommended for undisturbed sampling operations and is not discussed herein.

(a) *Free- or semifixed-piston samplers.* Free- or semifixed-piston samplers have overcome many of the shortcomings of open samplers while remaining easy to use. The piston is locked at the bottom of the sampler barrel as the sampler is lowered into the borehole. At the desired sampling depth, the piston is unlocked by rotating the drill rods. During the push, the piston rests on the sample entering the tube. Before the sampling tube is withdrawn, the piston rod is locked to prevent downward movement which aids in sample recovery. Free-piston samplers may be used in stiff clays or partially saturated silts and clays.

(b) *Fixed-piston samplers.* There are two basic types of fixed-piston samplers: the mechanically activated types, which include the Hvorslev and Butters samplers, and the hydraulically activated types, such as the Osterberg and modified Osterberg samplers. The basic principle of operation of fixed-piston samplers is the same as for thin-walled push-tube samplers, i.e., to force a thin-walled cylindrical tube into undisturbed soil in one continuous push without rotation. The piston is locked in a fixed position before, during, and after the sampler advance. As the sampler is lowered into the borehole, the piston is fixed relative to the cutting edge of the sampler to prevent foreign particles from entering the sample tube. Prior to sampling, the piston is fixed relative to the sample to be obtained. During the actual push, the piston moves with respect to the sampler and helps to pull the sample into the tube and to retain it following the drive. During withdrawal, the piston is again fixed relative to the sampler to aid in sample retention.

The principal use of fixed-piston samplers is for taking undisturbed samples of very soft to stiff clays, silts, and sands both above and below the water table (Goode, 1950). Fixed-piston samplers are particularly adapted to sampling cohesionless sands and soft, wet soils that cannot be sampled using the thin-walled open-tube sampler.

These samplers are designed for use in holes stabilized with drilling mud or water because the soil which is being sampled is generally below the water table. Sample tubes with little or no inside clearance ratio, or swage, are generally used with fixed-piston samplers. As is the case with all thin-walled push-tube samplers, the fixed-piston sampler will not successfully sample soils which contain gravel, cemented soil, or soils that are too hard to penetrate.

(i) *Mechanically activated fixed-piston samplers.*

(a) *Hvorslev fixed-piston sampler.* The Hvorslev fixed-piston sampler is a mechanically activated sampler which uses the drill rig hydraulic drive mechanism to advance the sample tube. The sampler head is designed for 7.5-cm- (3-in.-) diam tubes but can be easily converted to use 12.5-cm- (5-in.-) diam tubes with an adapter ring and an enlarged piston assembly. Figure 5-3 is a photograph of the Hvorslev fixed-piston sampler. Figure 5-4 is a cross-sectional view of the sampler.

The operation of the Hvorslev sampler is shown on Figure 5-5. First, the sampler is assembled with the piston locked flush with the bottom of the sampling tube. The sampler is then attached to the drill rods and piston rod extensions and lowered to the bottom of a cleaned borehole. When the sampler contacts the bottom of the hole, the drill rods are clamped to the hydraulic drive mechanism of the anchored drill rig. The piston rods are rotated clockwise to unlock the piston. The piston rods are then secured to the drill rig mast or a suitable frame independent of the drill rig for sampling operations. To sample, the sampler is advanced into the undisturbed soil in the same manner as described for the thin-walled push-tube sampler. At the end of the push, the piston rods are rotated counterclockwise to lock the piston on the sampler head. Further rotation in a counterclockwise direction causes the piston rods to be disconnected from the sampler. As a result, the piston rods can be removed before the sampler is withdrawn. During withdrawal, the piston remains locked at the top of its stroke by a split cone clamp. Extreme care must be exercised during removal of the sampler from the drill hole to avoid jarring or losing the sample.

The Hvorslev fixed-piston sampler contains many parts and several screw connections. Before attempting to use the apparatus, the operator should thoroughly understand the mechanics, adjustments, and operation of the sampler. Precision parts, such as the piston locking and releasing mechanism and the split cone clamp and spring, are easily damaged by misuse or incorrect assembly. Accurate

counting of rotations is required for proper operation and locking and releasing of the piston. As a general rule, the parts of the piston locking and releasing mechanism should be screwed together but not tightened excessively. A gap of 10 to 15 mm (3/8 to 1/2 in.) at the "Coupling with Nut Section" (Figure 5-4) is tightened to set the split cone clamp. Before the device is lowered into the borehole, the sampler should be assembled and checked for proper adjustment and ease of rotation of the locking mechanisms and operation of the device.

(b) *Butters fixed-piston sampler.* The Butters sampler is a simplified version of the Hvorslev sampler which contains fewer parts and screw connections. The Butters sampler has all right-hand threads and a simplified piston rod locking and unlocking mechanism. These features make the sampler much easier to operate. As with the Hvorslev sampler, the Butters sampler is designed for 7.5-cm- (3-in.-) diam push tubes. However, with an adapter ring and an enlarged piston assembly, the sampler is easily converted for use with 12.5-cm- (5-in.-) diam tubes. Figure 5-6 shows a cross-sectional view of the Butters sampler.

To operate, the sampler is assembled with the piston locked flush with the bottom of the sampling tube. The sampler is then attached to the drill rods and the piston rod extensions and lowered to the bottom of a cleaned borehole. When the sampler contacts the bottom of the borehole, the piston rod extensions are clamped to the anchored drill rig. After the piston rod extensions have been clamped, a clockwise rotation of the piston rods unlocks the piston. The piston rod is then secured to the drill rig mast or some other suitable frame which is independent of the drill rig. After the sampler has been advanced into the soil using procedures which are similar to those used for the thin-walled push-tube sampler, the piston rods are then disconnected from the sampler by turning in a counterclockwise direction until the piston rods are free. The piston rods are removed before the sampler is withdrawn. During withdrawal, the piston is held stationary at the top of its stroke by a tension spring and lock washers. Extreme care must be exercised during removal of the sampler from the drill hole to avoid jarring or losing the sample.

The basic rules for operation of the Butters sampler are similar to those of the Hvorslev sampler. Because the Butters sampler contains several parts which require careful assembly for locking and releasing the piston, the mechanics of the sampler should be understood thoroughly by the operator before attempting to sample, as the precision parts can be easily damaged by misuse or

incorrect assembly. In general, the parts of the piston rod locking and releasing mechanism should be screwed together snugly, but not tightened excessively. It is also good practice to assemble the sampler and to check its operation before it is lowered into the borehole.

(ii) *Hydraulically activated fixed-piston samplers.*

(a) *Osterberg fixed-piston sampler.* The Osterberg sampler is a hydraulically activated fixed-piston sampler. The design and operation of the hydraulically activated Osterberg sampler is significantly different from the design and operation of the mechanically activated Hvorslev and Butters samplers. Its operation is much faster and simpler than the Hvorslev and Butters samplers because piston rod extensions are not required. Therefore, the Osterberg sampler is much easier to assemble, operate, disassemble, and use. However, there are several disadvantages which include the lack of control for rate of or limit of advancement of the sampler as well as a vacuum breaker was not provided for separating the piston from the tube containing the soil sample. Figure 5-7 is a photograph of the Osterberg sampler. Figure 5-8 illustrates the operation of the sampler.

The Osterberg sampler is commercially available for use with sampling tubes of nominal diameters of 7.5 and 12.5 cm (3 and 5 in.). However, this sampler requires specially designed thin-walled sampling tubes. Conventional thin-walled sampling tubes used for the thin-walled open-drive sampler and the Hvorslev and Butters fixed-piston samplers will not adapt to the Osterberg sampler.

The Osterberg sampler is assembled with the piston flush with the bottom of the sampling tube and attached to the main head of the sampler. The sampler is attached to the drill string and lowered to the bottom of a cleaned borehole. The drill rods are secured to the anchored drill rig, and drilling fluid, under pressure, is pumped through the rods to advance the sampling tube into the undisturbed soil. As fluid pressure is applied to the inner sampler head, the sampling tube is forced out of the pressure cylinder. When the inner sampler head has reached its full stroke (and the sampling tube has penetrated its full depth into the soil), the pressure is relieved through a bypass port in the lower end of the hollow piston rod. An air bubble or return of drilling fluid can be observed at the top of the column of drilling mud which indicates that the sampler has been fully advanced. After the drive, the sampler should be rotated clockwise to shear the sample at the bottom of the sampling tube and to lock the sampling tube in position for withdrawal from the hole. The

rotation and locking of the sample tube is accomplished by a friction clutch mechanism which allows the inner sampler head to grasp the inner pressure cylinder when the drill rods are rotated at the ground surface. As the sampler is removed from the borehole, extreme care should be taken to avoid jarring or losing the sample.

Although the Osterberg sampler is relatively simple to operate, the mechanics of the sampler must be thoroughly understood by the operator before attempting to operate the sampler. The sampler contains several moving parts and O-ring seals which require careful assembly and must be kept clean and lubricated for proper operation. As a general rule, the threaded components should be screwed together snugly, but not tightened excessively. The fixed piston should be securely pinned to the hollow piston rod. The inner sampler head should be checked to make sure it slides freely on the hollow piston rod. The use of drilling mud to advance the sampler is not recommended because sand particles suspended in the mud act as an abrasive which may damage the O-ring seals. Therefore, a supply of clear water is desirable for advancing the sampler as well as for rinsing and flushing the sampler after each sampling drive although this may not always be practical in the field environment.

(b) *Modified Osterberg fixed-piston sampler.* The modified Osterberg sampler uses the same basic design and principles of operation as the conventional Osterberg sampler. However, there are several major changes and improvements to the modified Osterberg sampler as compared to the conventional Osterberg sampler. The thin-walled sampling tube was replaced with a thick-walled steel tubing which was machined to accept a commercially available aluminum inner liner. The thick-walled steel tubing is equipped with a case hardened, replaceable drive shoe. Consequently, the modified sampler is considerably more rigid and better suited for use in soils containing fine gravels. The design of the modified sampler also eliminates the problems associated with removing the sampling tube from the inner sampler head caused by the vacuum developed during the sampling operation. The thick-walled steel tubing has a vent hole to break the vacuum seal and to allow easy removal of the inner liner. The undisturbed sample can be removed from the sampler by simply removing the drive shoe and pulling the liner out of the sampler. The sampler can be reloaded by sliding a new liner into the steel tubing, attaching the drive shoe, and pushing the steel tubing into the pressure cylinder. Although the modified Osterberg sampler is not commercially available, it can be manufactured in 7.5- and 12.5-cm- (3- and 5-in.-) diam sizes.

(c) *Foil and stockinette samplers.* Modified versions of the fixed-piston sampler include the Swedish foil sampler and the Delft stockinette sampler. The principle of operation of these samplers is similar to the fixed-piston sampler. As the sampler is pushed, the piston retracts from the sampler head, and a sliding liner which is attached to the piston is unrolled from its magazine located within the sampler head. Both types of samplers are pushed into the soil without a borehole.

The Swedish foil sampler was developed to obtain long, continuous undisturbed samples in soft cohesive soils (Kjellman, Kallstenius, and Wager 1950). To reduce the friction between the soil sample and the sampler barrel, the sample is progressively encased in thin axial strips of foil as the sampler is advanced. Two diameters of foil samplers are available. The 6.8-cm- (2.7-in.-) diam sampler contains 16 rolls of thin, cold-rolled, mild steel foil in the sampler head. Each roll of foil is approximately 12.5 mm (0.5 in.) wide. The foil is available in thicknesses ranging from 0.05 to 0.12 mm (0.002 to 0.005 in.). The 6.8-cm- (2.7-in.-) diam sampler can store 30 m (100 ft) of foil, while the 4.0-cm- (1.6-in.-) diam sampler can store 12 m (40 ft) of foil. A schematic of the Swedish foil sampler is presented in Figure 5-9.

The Swedish foil sampler consists of a cutter head which is machined to form a sharp edge. The cutter head is attached to the lower end of the sample barrel. The upper end of the cutter head is double-walled and contains a magazine for the rolls of foil. The foil strips pass through small horizontal slots located immediately above the cutter edge and are attached to a loose-fitting piston. During sampling operations, the piston is held stationary at the ground surface to ensure that the foil strips are pulled from the magazine at the same rate as the sampler penetrates the soil.

The foil strips which slide against the inside of the sampler barrel form an almost continuous liner which minimizes the friction between the sampler wall and soil sample. As with the conventional push-tube type samplers, the full advance of the sampler should be made in one fast, smooth, continuous push. However, the effects of the rate of penetration and/or interruptions in pushing are less important. Therefore, additional 2.5 m (8.2 ft) long sections of the sample barrel may be added to extend the length of the sampler.

The original Delft continuous soil sampler was used to obtain a sample 30 mm (1.2 in.) in diameter. As the sampler was pushed into the ground, a nylon stocking-type reinforced plastic skin was unrolled from a magazine

in the sampler head to surround the outside of the sample. As the stocking was unrolled, it was coated with a vulcanizing fluid which was stored in a chamber between the stocking tube and the outer barrel of the sampler. When the coated stocking contacted the bentonite-water slurry inside the sampler, the vulcanizing fluid solidified. As a result, the stockinette became a watertight container which prevented lateral strain of the soil sample.

Unfortunately, the bentonite-water slurry in the annulus between the soil sample and sampler sometimes exceeded the in situ stresses, especially in soft soils. As a result, the soil sample and surrounding formation were disturbed. Consequently, the Delft continuous soil sampler was redesigned. The current version can be used to obtain a 66-mm- (2.6-in.-) diam sample. The sampler uses a stocking-lined plastic liner tube which supports the soil sample during the sampling operations and doubles as the sample storage tube. A schematic of the Delft 66-mm- (2.6-in.-) diam continuous soil sampler is presented in Figure 5-10. The Delft continuous soil sampler is advanced in 3.3-ft (1-m) increments by a cone penetrometer test (CPT) rig. The maximum length of the sample is 19 m (62 ft).

The foil and stockinette samplers were designed to obtain samples with an increased length to diameter ratio which are sometimes required to gain a more comprehensive understanding of a complex soil mass, such as a varved clay, or to obtain samples of soft clay or peat. Although the soil friction inside the sampler is virtually nonexistent, the frictional forces between the foils or stockinette and the inside walls of the sampler and between the soil and outside walls of the sampler can become so great as to prohibit pushing the sampler. Lubricants have been used between the liners and sampler for cohesive soils, but should not be used for cohesionless soils as they may penetrate the sample and prohibit its use. Friction between the soil and the outside of the sampler has been reduced by the use of a rotary outer core barrel which has cutter teeth and the capability of circulating a drilling fluid. The principal disadvantages of the foil and stockinette samplers include larger operating expenses and the increased potential for sample disturbance due to the larger area ratio of the cutting shoe.

b. Core barrel samplers. Double- and triple-tube core barrel samplers consist of a sampler head assembly, inner and outer tubes, and a bottom assembly. The triple-tube core barrels are merely double-tube samplers which have been modified to accept sample liners. The principle of operation of the core barrel samplers consists of rotating a cutting bit by a torque which is applied at the

ground surface by the drill rig and transmitted downward through the drill rods to the cutting bit. As the cutting edge is advanced, a sampling tube is pushed over the sample. The sampler head assembly has a ball-bearing-supported cap and stem which allows the inner tube to remain relatively stationary as the outer barrel is rotated. Drilling fluid is passed downhole through the drill rods and between the inner and outer barrels before being discharged under the bit.

There are three basic types of core barrel soil samplers: Denison, Pitcher, and hollow-stem auger samplers. The Denison and Pitcher samplers are similar in design and operation. These samplers require the use of drilling fluid to remove the cuttings from the face of the bit. The hollow-stem auger sampler which is discussed in paragraph 5-1c(1) does not require drilling fluid; therefore, is well suited for sampling soils that are adversely affected by drilling fluids. Sample liners for handling and shipping the soil cores can be used with the Denison and hollow-stem auger samplers.

Core barrel samplers may have a larger area ratio and inside clearance ratio than is generally accepted for push-tube samplers. Double- and triple-tube core barrel samplers are available in standard sizes ranging from 7.0-cm (2-3/4-in.) ID by 9.8-cm (3-7/8-in.) OD to 15.2-cm (6-in.) ID by 19.7-cm (7-3/4-in.) OD. The larger area ratios may be considered advantageous as the stresses at the cutting head are decreased during the drilling operations. However, the larger inside clearance ratio due to a core catcher may not adequately support the sample. The sample may also be damaged by vibrations of the cutting bit during the drilling operations. Another disadvantage is that water sensitive formations may be continuously in contact with the drilling fluid.

Core barrel samplers may be used for sampling a broad range of soils. These samplers can be used for obtaining reasonably undisturbed samples of stiff cohesive soils. Firm or dense samples of uncemented or lightly cemented silty or sandy soils can often be obtained if sampling and handling of the samples are done carefully. However, when it is unknown whether the deposit is dense or loose, other samplers, such as fixed-piston samplers, should be tried as the core barrel samplers tend to densify loose soils during the sampling operations. Core barrel samplers may also be used in fairly firm to hard or brittle soils, partially cemented soils, and soft rock which require a cutting action rather than simply a push-type penetration. In general, core barrel samplers, such as the Denison and Pitcher samplers, are not suitable for sampling loose cohesionless sands and silts below the

groundwater table, very soft and plastic cohesive soils, or severely fissured or fractured materials.

(1) *Denison sampler.* The Denison sampler is a double-tube (triple-tube if a liner is used) core-barrel type sampler designed for sampling coarse sands, gravel and gravelly soils, and clays and silts that are too hard to sample with thin-walled push-tube samplers. The sampler consists of an outer barrel with cutting teeth, an inner barrel with a smooth cutting shoe, and a liner to receive the sample and to facilitate sample handling. The inner barrel may be equipped with a spring core catcher, if necessary. Denison samplers are available in 10.0- and 15.0-cm- (4- and 6-in.-) nominal diameter core sizes. The length of the cores are 0.6 m (2 ft). A photograph of a Denison double-tube core barrel sampler is presented in Figure 5-11. A schematic diagram of the sampler is shown in Figure 5-12.

The Denison sampler is advanced in the borehole using drilling rod and drilling fluid. The outer barrel head contains an upper and lower bearing which allows the outer barrel to be turned by the drilling rod while the inner barrel remains stationary. Carbide insert cutting teeth are attached to the bottom of the outer barrel. Four 1.25-cm- (1/2-in.-) diam fluid passages are used for circulation of drilling fluid from the drill rods into the annulus between the inner and outer barrels to the cutting teeth. Four 1.25-cm- (1/2-in.-) diam holes are also provided in the outer barrel head to vent the inner barrel and to stabilize the hydrostatic pressure within the sampler.

The Denison sampler may be fitted with inner barrel shoes of various lengths. This shoe arrangement effectively permits the inner barrel to be extended beyond the cutting bit, especially for coring and sampling easily eroded material. The inner barrel may be extended as much as 15.0 cm (6 in.) past the cutting bit, although an extension no greater than 7.5 cm (3 in.) is recommended. Unfortunately, the principal disadvantage of this type of sampler is that the protrusion of the inner tube must be selected and/or adjusted in advance of the sampling operations for the anticipated stiffness of the soil to be sampled. This disadvantage led to the development of core barrel samplers with the spring-mounted inner barrel.

A light gauge metal liner which can be used as a sampling tube to preserve the soil sample for shipment can be fitted into the inner barrel of the Denison sampler. The liner is typically made of 28-gauge (0.38-mm) sheet metal. The length of the liner should be 60 cm (24 in.); this length will permit a 50-cm-(20-in.-) long sample to be obtained. A core catcher may or may not be used for

undisturbed sampling operations. However, if a core catcher must be used to retain the soil in the sampler, it should be noted on the boring logs.

(2) *Pitcher sampler.* The Pitcher sampler is a double-tube core barrel sampler which is a variation of the Denison sampler. The inner barrel which is affixed to a spring-loaded inner sampler head extends or retracts relative to the cutting bit on the outer barrel with changes in soil stiffness. The telescoping action of the sampling tube eliminates the need for various lengths of inner barrel shoes. The nominal core sizes which can be obtained with standard Pitcher samplers are 75-, 100-, and 150-mm (3-, 4-, and 6-in.) diameter with lengths of 0.9 or 1.5 m (3 or 5 ft). Figure 5-13 is a photograph of a Pitcher double-tube core barrel sampler. A schematic drawing of the operation of the Pitcher sampler is presented in Figure 5-14.

The Pitcher sampler contains a high-tension spring which is located between the inner and outer barrels above the inner head. The spring-loaded inner barrel assembly automatically adjusts the relative position of the cutting edge of the sampling tube to suit the formation being sampled. For example, in softer formations, the spring extends so that the inner barrel shoe protrudes into the soil below the outer barrel bit and prevents damage to the sample by the drilling fluid and drilling action. For stiffer soils, the sampling tube is pushed back into the outer barrel by the stiff soil. In extremely firm soils, the spring compresses until the cutting edge of the inner barrel shoe is flush with the crest of the cutting teeth of the outer barrel bit. Although it has been observed in practice that alternating soil and rock layers sometimes damage the rather light sampling tube, the Pitcher sampler is recommended for sampling varved soils, formations where the stratigraphy is such that there are alternating hard and soft layers, or soils of variable hardness.

A sliding valve arrangement between the outer barrel head and inner barrel head directs drilling fluid through the sampler. After the sampler has been lowered into the borehole but before it has been seated on the soil, debris can be flushed from the sample tube by drilling fluid which is passed down the drill rods through the inner barrel. Once the inner tube is seated, the barrel telescopes inward and the drilling fluid is diverted to the annulus between the inner and the outer barrels. This arrangement facilitates the washing of material from the inside of the sampler before sampling and circulation of drilling fluid to remove cuttings during sampling.

(3) *WES modified Denison sampler.* A special sampler was developed by the U.S. Army Engineer Waterways Experiment Station (WES) to obtain samples of hard or gravelly soils and rock. The sampler incorporates principles used in the Denison core barrel sampler; hence, it is called the modified Denison sampler. The sampler was designed to obtain an undisturbed sample in a 127-mm- (5.01-in.-) ID by 133-mm- (5.25-in.-) OD steel tube that could later be cut in sections for testing without removal of the soil from the tube. The sampler consists of a standard DCDMA 100-mm (4-in.) by 140-mm (5.5-in.) core barrel head adapted to a 150-mm- (6-in.-) OD outer barrel and a standard 125-mm (5-in.) by 11-gauge (3-mm) sample tube. Two outer barrel cutting shoe arrangements permit the inner barrel cutting edge to lead or to follow the outer barrel cutting shoe. An inner barrel adapter is provided with spacers to vary the relative positions of the two barrels. Core barrels with internal or bottom discharge bits set with tungsten carbide teeth are satisfactory for drilling and sampling most stiff to hard soils. The cutting teeth are set at 20 to 30 deg with respect to the radius to cause a slicing action which tends to force the cuttings and drilling fluid away from the core. The bottom assembly can be fitted with an inner tube extension and cutting shoe. Bottom assemblies are also available which permit the use of basket-type or split-ring core lifters to prevent the loss of the core during the extraction process. A third cutting shoe arrangement allows the use of a diamond bit and a split-ring core lifter. The nominal core size is 125 mm (5 in.) in diameter by 0.76 m (2.5 ft) in length.

c. Other samplers. A number of other samplers suitable for obtaining undisturbed samples are available from commercial sources. Generally, each sampler was designed to be used in specific types of soils or to satisfy specific conditions. However, most of these samplers are variations of either the thin-walled piston-type samplers or the core barrel samplers.

(1) *Hollow-stem auger sampler.* The continuous hollow-stem auger sampling system consists of a rotating outer hollow-stem auger barrel which is equipped with cutting bits at its bottom and a nonrotating inner barrel (sampler) fitted with a cutting shoe. The principle of operation is similar to the rotary core barrel sampler. The stationary inner barrel slides over the sample in advance of the rotating outer bit which enlarges the hole above the sample. The cuttings are lifted from the hole by the auger flights on the outer barrel. A schematic drawing of

the hollow stem auger with a thin-walled sampling tube is presented in Figure 5-15.

The hollow-stem auger barrel acts as a casing in the borehole. It is defined by pitch, flight, outside diameter, and inside diameter. Augers range in diameters from 57 mm (2-1/4 in.) to 210 mm (8-1/4 in.), or larger. A table of common diameters of flight augers is presented as Table 5-1. The hollow-stem auger barrel is advanced by downward pressure to clean the hole and rotation to bring the cuttings to the surface. Excessive downfeed pressure may cause the auger to corkscrew into the ground. As a result, the auger could bind in the hole. Additional sections of auger can be added as the borehole is advanced.

The cutting bits on the hollow-stem auger barrel are equipped with 4 to 12 cutting teeth which are fitted with replaceable carbide inserts. The ID of the cutting bits allows clearance for passage of the inner barrel. During sampling operations, the inner barrel is pinned to and advanced with the hollow-stem auger. The inner barrel may be positioned in front of or kept even with the auger cutting bits with an adjustment rod. Minimal disturbance to the sample is caused when the inner barrel is advanced in front of the cutting teeth by approximately 75 mm (3 in.). When the inner barrel is advanced in front of the cutting teeth by less than 75 mm (3 in.), disturbance may occur because of the ripping action of the auger cutting teeth.

The inner barrel assembly contains a sampler head and liner. The inner barrel assembly can be fitted with one 1.5-m (5-ft) liner section or two 0.76-m (2-1/2-ft) liner sections. The liners can be acrylic or metal. Acrylic tubing is economical and permits visual inspection of the sample. It is reusable but should be checked for cracks, roundness, and wall thickness before reuse. Metal liners generally have less wall friction than acrylic liners.

The liners are held in the inner barrel assembly by a cutting shoe which is threaded onto the inner barrel assembly. The cutting shoes may be machined with different inside clearance ratios. (See paragraph 2-3b for the inside clearance ratio calculation procedure.) The selection of the inside clearance ratio of the cutting shoe will depend on the soil to be sampled. In general, smaller inside clearance ratios should be used for cohesionless soils, whereas larger clearance ratios should be used as the plasticity of the material increases.

Continuous sampling is possible as the auger advances the borehole. When sampling is not required, a center bit can be used to keep soil out of the hollow stem of the auger.

The center bit is a left-handed auger which forces the parent material down and to the outside of the main auger barrel, thereby allowing the main auger barrel to carry the cuttings to the surface. The center bit can be replaced with the inner barrel assembly at any time or depth to permit samples to be taken.

The principal advantages of the continuous hollow-stem auger sampling system include advancing the borehole in dry materials without drilling fluid or in unstable materials without casing. Whenever augering operations are conducted below the water table, hydrostatic pressures should be maintained at all times inside the hollow stem to prevent heaving and piping at the bottom of the borehole. If the center plug is used, O-rings should be used to keep water out of the auger stem.

An alternative method of sampling with a hollow-stem auger consists of advancing the borehole by augering with a center drag bit attached to the bottom of the auger. At the desired sampling depth, the center bit is removed, and a suitable sampling apparatus is lowered through the auger to obtain a sample. For this particular application, the hollow-stem auger is used as a casing. Figure 5-16 is a photograph of a hollow-stem auger with a center drag bit. An isometric drawing of the hollow-stem auger with the center drag bit which can be used with soil sampling devices is presented in Figure 5-17.

(2) *Sand samplers.* Obtaining undisturbed samples of sand has been rather difficult and elusive. In general, the in situ stresses are relieved by sampling operations and frequently, the sand structure has been disturbed and sometimes destroyed. Hvorslev (1949) suggested several methods including the use of thin-walled fixed-piston samplers in mudded holes, open-drive samplers using compressed air, in situ freezing, or impregnation. USAEWES (1952) and Marcuson and Franklin (1979) reported that loose samples were densified and dense samples were loosened when the thin-walled fixed-piston sampler was used. Seed et al. (1982) reported that the Hvorslev fixed-piston sampler caused density changes, while the advanced trimming and block sampling technique caused little change in density, although some disturbance due to stress relief was reported. Singh, Seed, and Chan (1982) reported a laboratory study which indicated that the in situ characteristics, including the applied stress conditions, could be maintained in a sandy soil if the material was frozen unidirectionally without impedance of drainage and sampled in a frozen state. Equipment and procedures for drilling and sampling in frozen formations are presented in Chapter 9; suggested equipment and procedures for artificial freezing of in situ

deposits of cohesionless soils are presented in Appendix D. Schneider, Chameau, and Leonards (1989) conducted a laboratory investigation of the methods of impregnating cohesionless soils. They reported that the impregnating material must readily penetrate the soil and must be easily and effectively removed at a later date. Because of these limitations, they also concluded that although the impregnation method could be used in the field environment, the methodology was better suited to the laboratory environment.

Bishop (1948) developed a 63-mm- (2-1/2-in.-) diam thin-walled open-drive sampler which was specifically designed for sampling sand. The sampler was equipped with vents and a diaphragm check valve. Figure 5-18 is a schematic diagram of the Bishop sand sampler. A drawing which illustrates the operation of the Bishop sampler is presented in Figure 5-19. The entire sampler was encapsulated in a compressed air bell which was connected to an air compressor at the ground surface. To operate, the sampler with compressed air bell was lowered to the bottom of a cleaned borehole. The sampling tube was pushed out of the air bell and into the undisturbed soil. After the drilling rods had been disconnected from the sampler and removed from the borehole, compressed air was pumped into the bell. When air bubbles began rising to the surface through the drilling fluid, all of the drilling fluid had been forced out of the compressed air bell. The sampling tube with the sample was pulled from the in situ formation into the bell, and the entire assembly was quickly returned to the ground surface by a cable. Bishop used the principles of arching and capillary stresses at the air-water interface of the sand to retain the sample in the tube and to reduce sample losses.

Vibratory samplers have been used to obtain samples of saturated fine sands and silts. The principle of sampling by vibratory methods consists of liquefying the material in the immediate proximity of the sampling rather than applying brute force to advance the tube. Because of the liquefaction of the material near the sampling tube, the sample is severely disturbed. Consequently, the vibratory sampling method is not satisfactory for obtaining undisturbed samples of sands.

5-2. Sample Tubes

a. Diameter. The size of specimen required for the laboratory testing program shown in Table 2-5 dictates the minimum acceptable sample tube diameter. Generally, a 125-mm (5-in.) ID tube should be used for sampling cohesive soils, whereas a 75-mm (3-in.) ID tube should be used for sampling cohesionless soils. Figure 5-20 is a

photograph of 75- and 125-mm- (3- and 5- in.-) diam sampling tubes. The smaller diameter tubes are normally used for sampling cohesionless materials because the penetration resistance of the 125-mm (5-in.) tubes in dense cohesionless soils generally exceeds the driving capacity of the drill rig. Furthermore, the sample recovery ratio for cohesionless materials is frequently higher when the 75-mm (3-in.) ID tube is used because of arching of the material in the sample tube. Although larger samples are sometimes required for special testing programs, 75- and 125-mm- (3- and 5-in.-) diam sampling tubes should be used to the extent possible to permit standardization of sampling equipment and procedures and to ensure that sample sizes are compatible with laboratory testing equipment and requirements.

b. Length. Sample tubes must be long enough to accommodate the sampler head and piston of the given sampling apparatus and to obtain a sufficient length of sample. Typically, the length of the sample tube is about 0.9 m (3 ft) which is sufficient for obtaining a 0.75-m (2.5-ft-) long sample.

c. Area ratio. As discussed in paragraph 2-3, the sample tube wall should be as thin as practical but strong enough to prevent buckling of the tube during sampling. Sample tubes of 125-mm (5-in.) ID by 11-gauge (3-mm) wall thickness or 75-mm (3-in.) ID by 16-gauge (1.5-mm) wall thickness cold-drawn or welded and drawn-over-the-mandrell seamless steel tubing provide adequate strength and an acceptable area ratio. The area ratio for a 125-mm (5-in.) ID by 11-gauge (3-mm) sample tube with a 1.0 percent swage is approximately 12 percent. The area ratio for a 75-mm (3-in.) ID by 16-gauge (1.6-mm) sample tube with 0.5 percent swage is approximately 10 percent.

d. Cutting edge. The sample tube for undisturbed samples should have a smooth, sharp cutting edge free from dents and nicks. The cutting edge should be formed to cut a sample 0.5 to 1.5 percent smaller than the ID of the sample tube. As discussed in paragraph 2-3, the required clearance ratio, or swage, must be varied for the character of the soil to be sampled. Sticky, cohesive soils require the greatest clearance ratio. However, swage should be kept to a minimum to allow 100 percent sample recovery.

e. Material.

(1) *Tubing.* Sampling tubes should be clean and free of all surface irregularities including projecting weld seams. Cold-drawn seamless steel tubing provides the

most practical and satisfactory material for sample tubes. Generally, tubing with a welded seam is not satisfactory. However, welded and drawn-over-the-mandrel steel tubing is available with dimensions and roundness tolerances satisfactory for sample tubes. Brass or stainless steel tubing is also satisfactory provided that acceptable tolerances are maintained. However, the extra cost for brass or stainless steel tubing is justified only for special projects.

(2) *Coating.* Steel sampling tubes should be cleaned and covered with a protective coating to prevent rust and corrosion which can damage or destroy both the unprotected tube and sample. The severity of the damage is a function of time as well as the interaction between the

sample and the tube. Hence, the material to be sampled may influence the decision regarding the type of coating which is selected. It is also noteworthy that the protective coating helps to form a smoother surface which reduces the frictional resistance between the tube and the soil during sampling operations.

Coatings may vary from a light coat of oil, lacquer, or epoxy resin to teflon or plating of the tubes. Alternate base metals for the tubes should also be considered for special cases. Mathews (1959) describes the results of tests conducted at WES on a variety of sample tube coatings. A photograph of a dipping tank for coating 75- and 125-mm- (3- and 5-in.-) diam sampling tubes is illustrated in Figure 5-21.