PDHonline Course C330 (3 PDH)

Sampling Frozen Soils

Instructor: John Huang, Ph.D., PE and John Poullain, PE

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
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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 Dennison 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 2-3*b* 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.

Table 5-1
Auger Sizes (Diameters) (after Acker 1974)

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

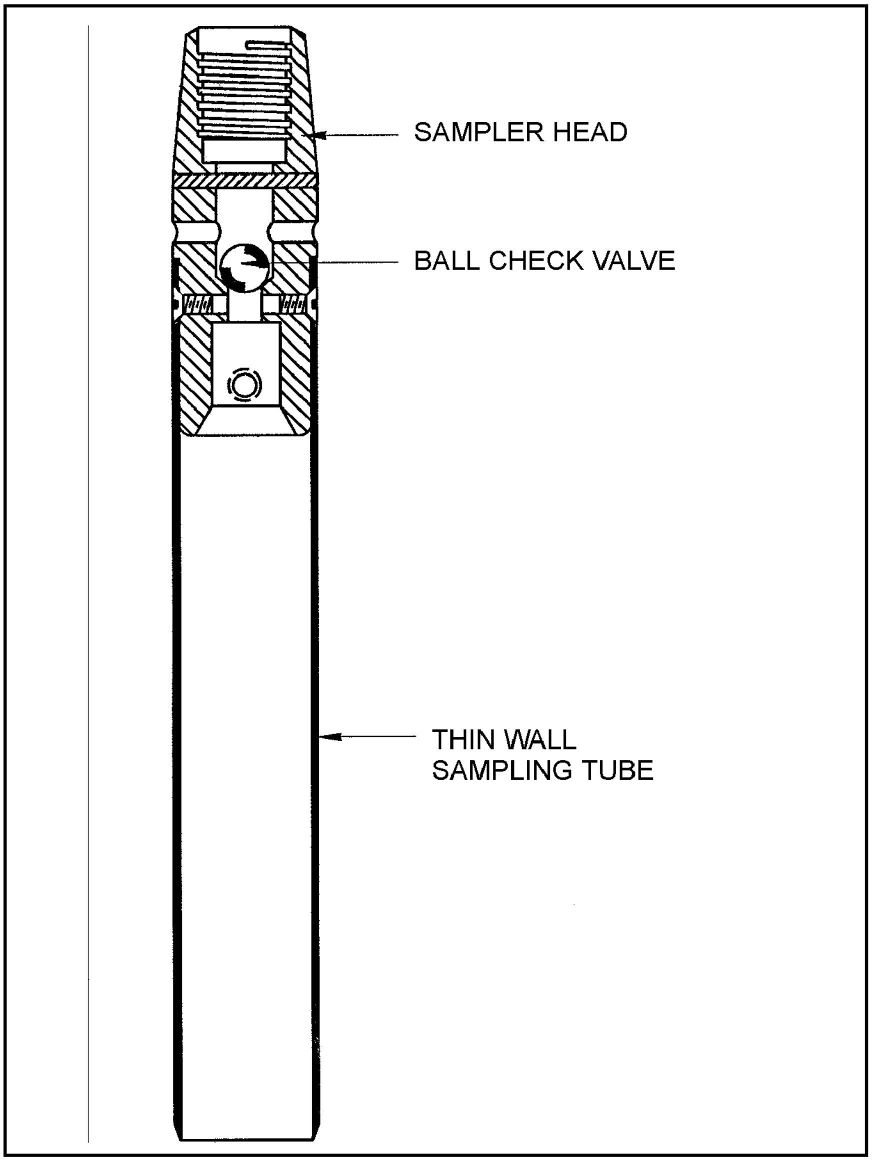

Figure 5-1. Schematic drawing of an open-tube sampler

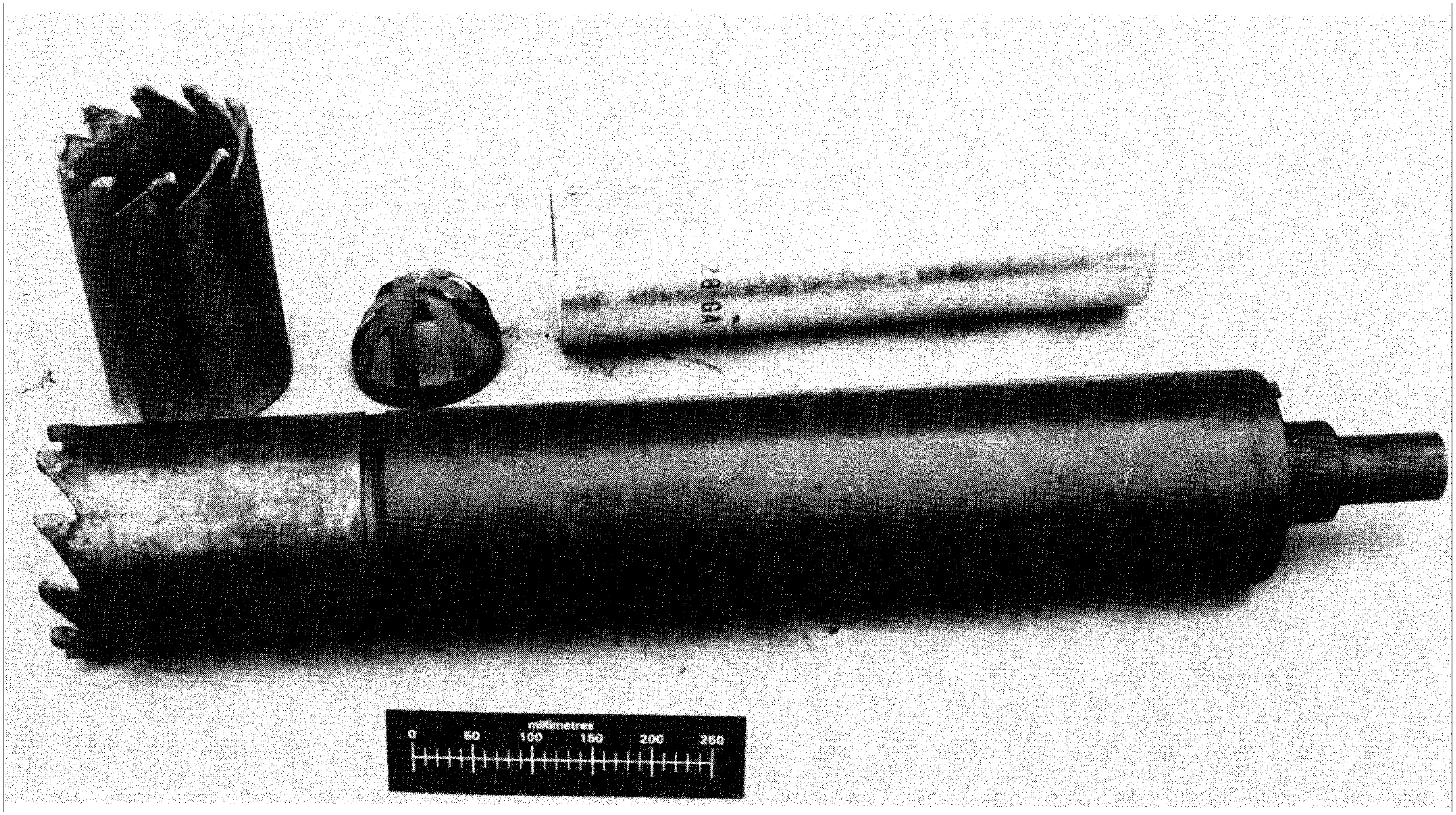

Figure 5-11. Photograph of the Denison sampler

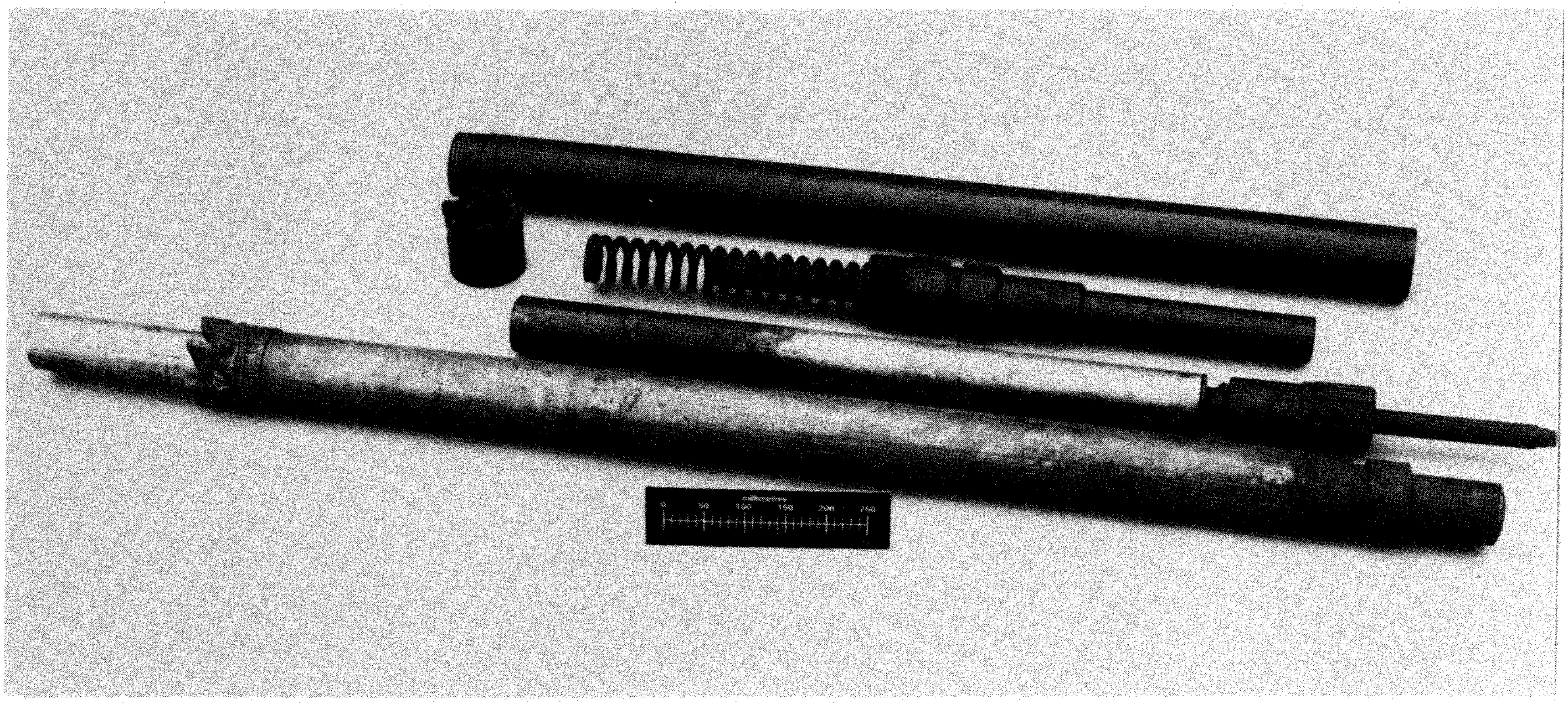

Figure 5-13. Photograph of the Pitcher double-tube core barrel sampler

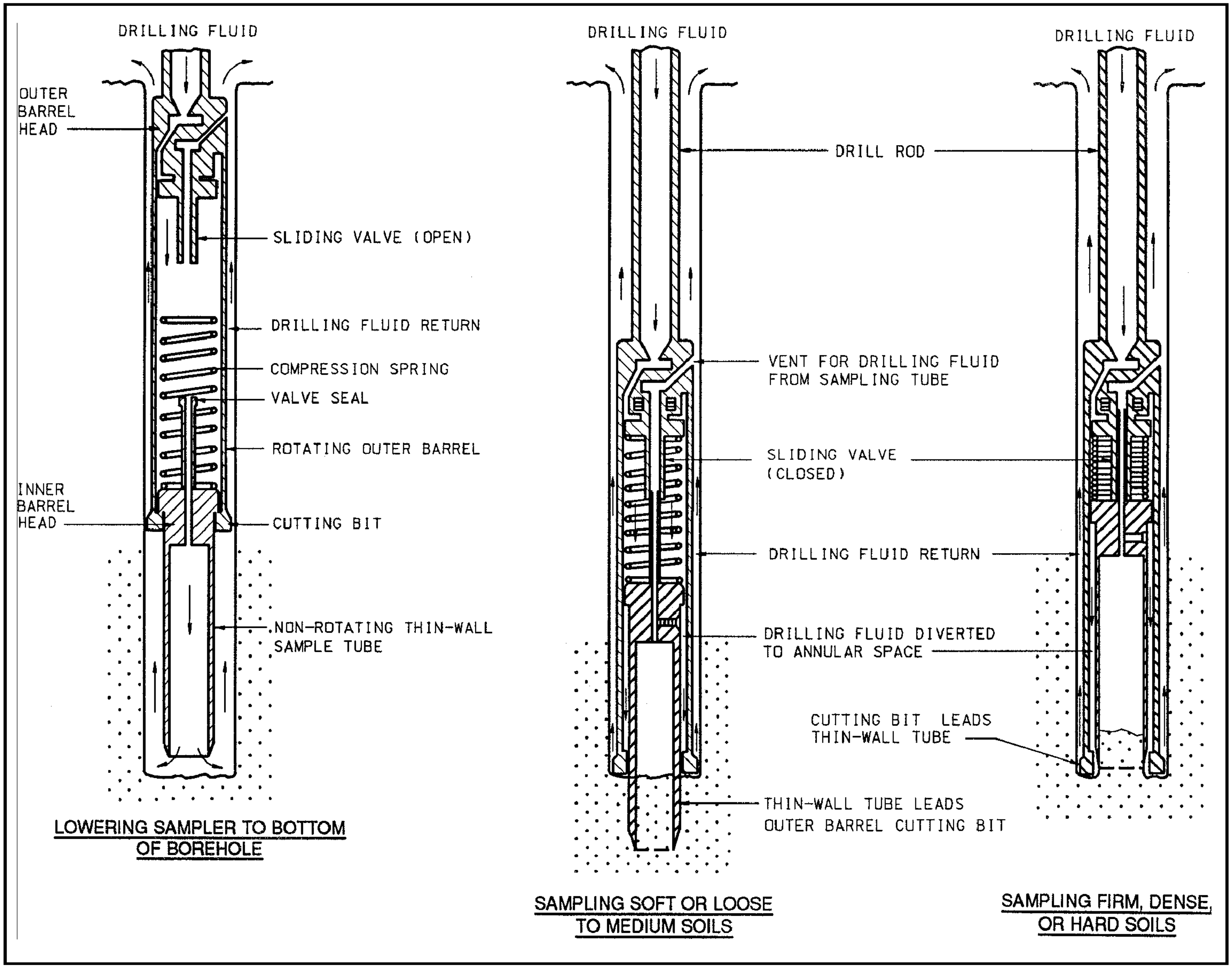

Figure 5-14. Schematic drawing of the operation of the Pitcher sampler (after (Winterkorn and Fang 1975)

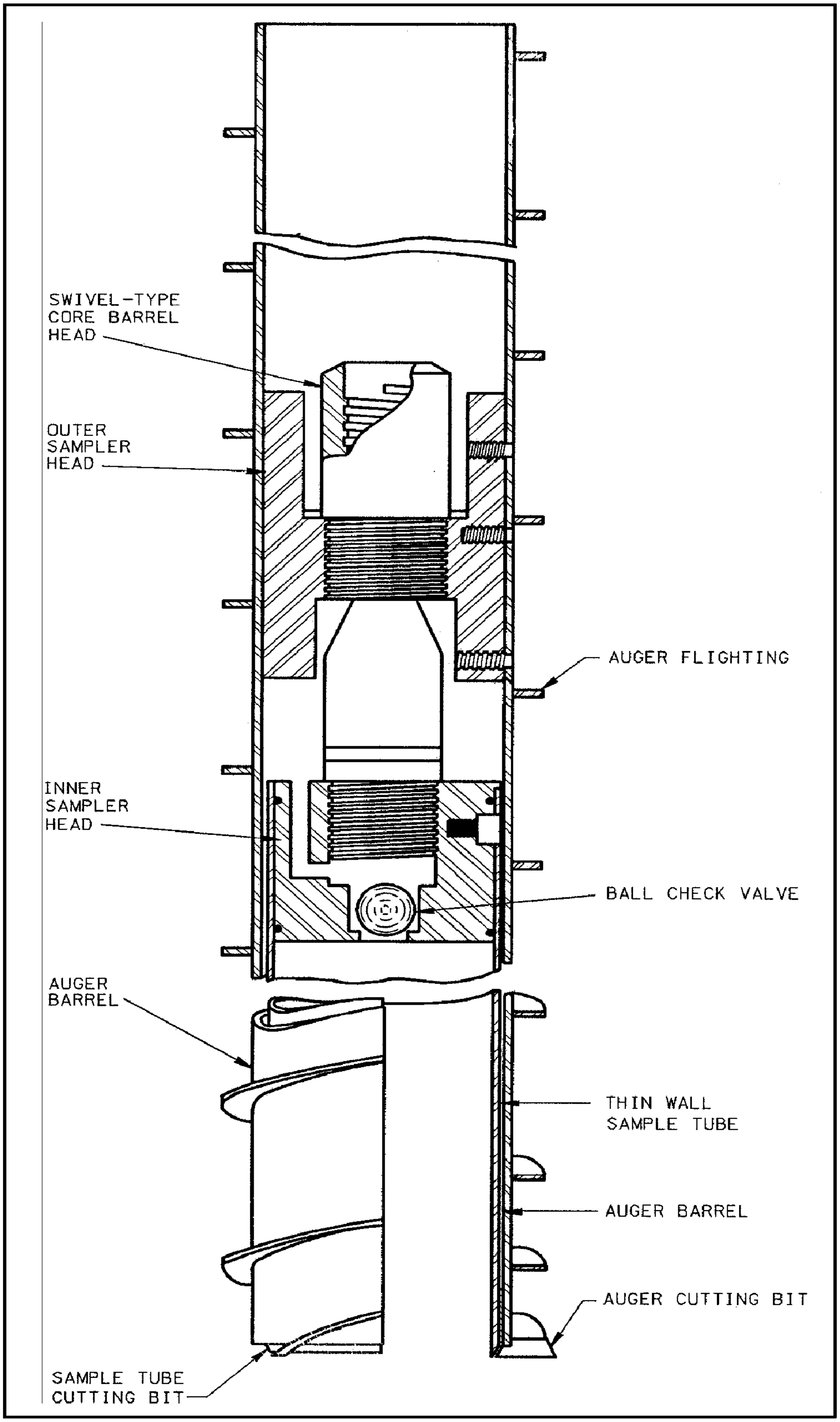

Figure 5-15. Schematic drawing of a hollow-stem auger with thin-wall sampling tube (after U.S. Department of the Interior 1974)

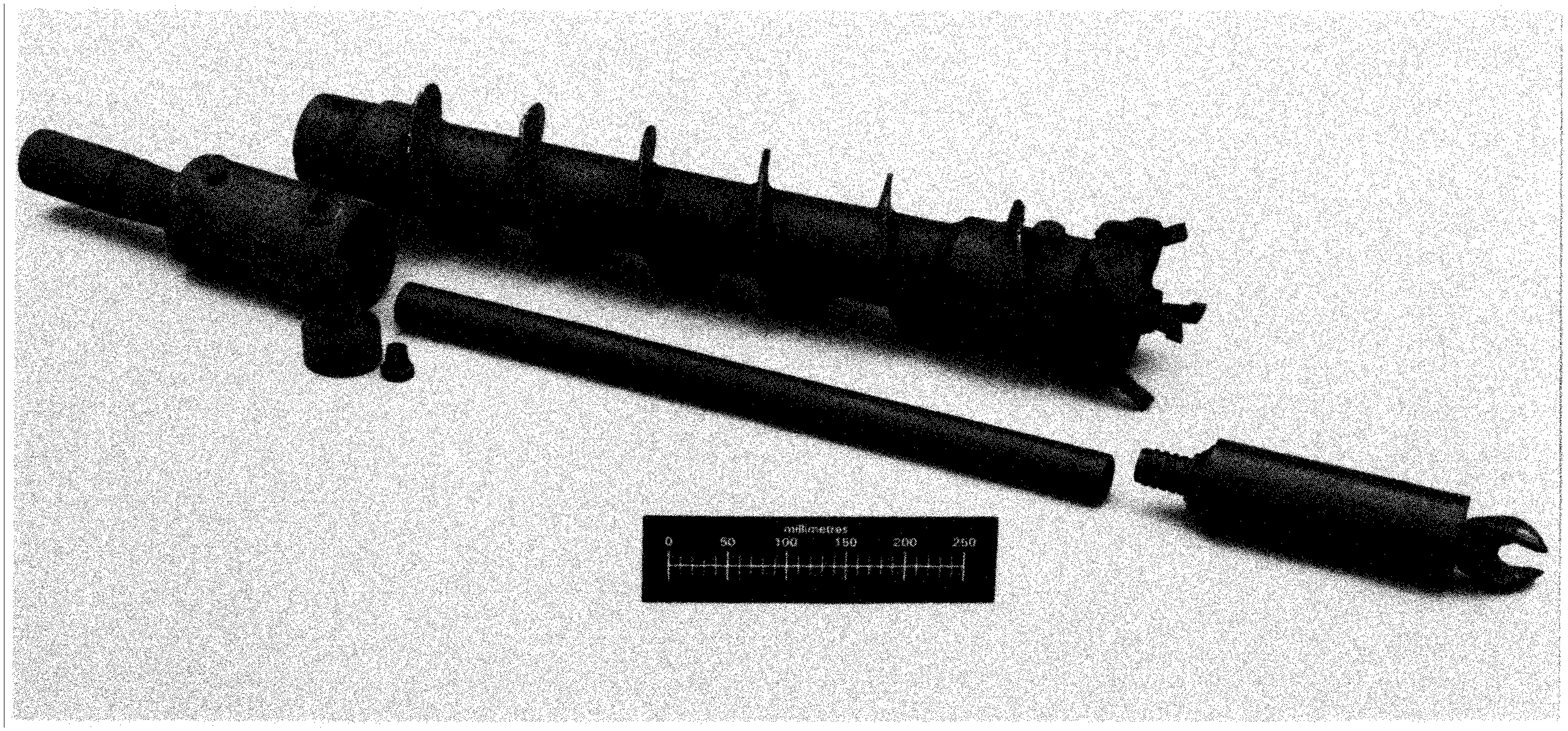

Figure 5-16. Photograph of a hollow-stem auger with a center drag bit

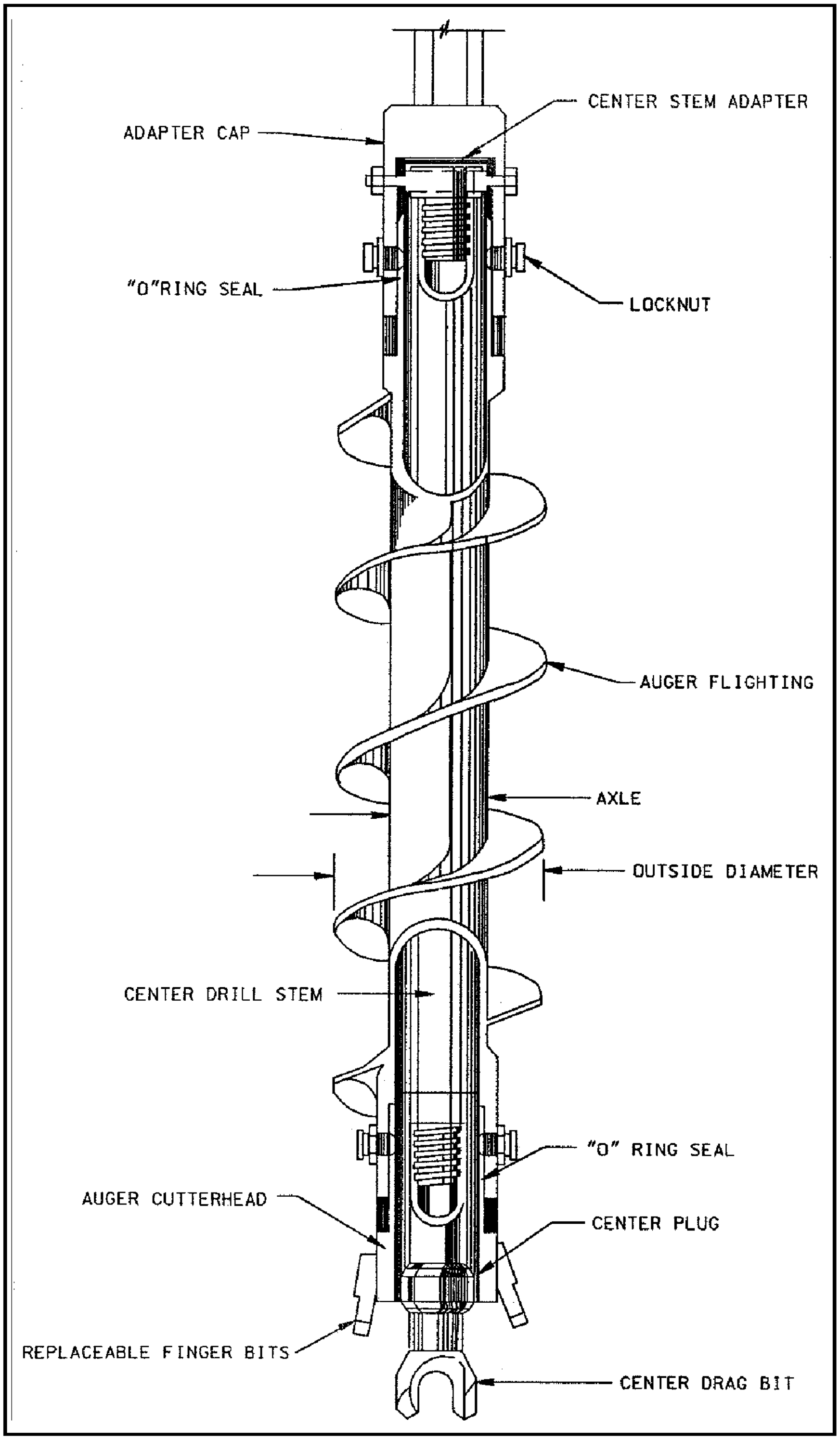

Figure 5-17. Isometric drawing of the hollow-stem auger with the center drag bit which can be used with soil sampling devices (after Acker 1974)