Appendix B
Penetration Resistance Test and Sampling with a Split-Barrel Sampler

B-1. Introduction

The method of sampling soil described herein consists of driving a split-barrel sampler to obtain a representative, disturbed sample and to simultaneously obtain a measure of the resistance of the subsoil to penetration of a standard sampler. The resistance to penetration is obtained by counting the number of blows required to drive a steel tube of specified dimensions into the subsoil a specified distance using a hammer of a specified weight (mass). This test is commonly referred to as the Standard Penetration Test (SPT). The soil sample which is obtained as a part of the test can be used for water content determination, soil-type identification purposes, and laboratory tests in which the degree of disturbance of the sample does not adversely affect the results. See Chapters 7 and 8 for additional information on sampling with open tube samplers.

The results of the SPT have been used extensively in many geotechnical exploration projects. The SPT blowcount, N, is a measure or index of the in-place firmness or denseness of the foundation material. Many local correlations as well as widely published correlations which relate SPT blowcount and the engineering behavior of earthworks and foundations are available. Because the SPT is considered to be an index test, blowcount data should be interpreted by experienced engineers only.

In general, the SPT blowcount data are applicable to fairly clean medium-to-coarse sands and fine gravels at various water contents and to saturated or nearly saturated cohesive soils. When cohesive soils are not saturated, the penetration resistance may be misleading of the behavior of the material as a foundation soil. Likewise, the engineering behavior of saturated or nearly saturated silty sands may be underestimated by the penetration resistance test.

The relative firmness or consistency of cohesive soils or density of cohesionless soils can be estimated from the blowcount data which is presented in Table B-1. The bearing capacity of cohesionless and cohesive soils can also be estimated from the SPT blowcount data. For blowcounts in excess of 25 blows, the bearing capacity is excellent. For blowcounts less than 10 blows, the bearing capacity is poor. Hard, saturated cohesive soils and dense to very dense cohesionless soils will support moderately heavy- to heavy loads, whereas very firm cohesive soils and medium dense- to dense cohesionless soils are adequate for most lighter loads.

B-2. Equipment and Terminology

A qualitative measurement of the dynamic penetration resistance of soil is obtained by driving a split-spoon sampler. To be meaningful, the value of penetration resistance must be obtained with standardized equipment and procedures. The following paragraphs describe the standard equipment which is required for the SPT and the associated terminology. The description of the equipment and the terminology are generally compatible with ASTM D 1586-84, "Standard Method for Penetration Test and Split-Barrel Sampling of Soils" (ASTM 1993)[1] and the SPT procedure recommended by the International Society for Soil Mechanics and Foundation Engineering, "Standard Penetration Test (SPT): International Reference Test Procedure" (Decourt et al. 1988).

a. Incremental blowcount. ΔN is the number of blows for each 150-mm (6-in.) interval of sampler penetration for the 0- to 150-mm (0- to 6-in.) interval, for the 150- to 300-mm (6- to 12-in.) interval, and for the 300- to 450-mm (12- to 18-in.) interval.

b. Blowcount. N is the blowcount representation, in blows per foot, of the penetration resistance of the soil. The SPT N-value equals the sum of the blows of the hammer which are required to drive a standard sampler for the depth interval from 150 to 300 mm (6 to 12 in.) plus the depth interval from 300 to 450 mm (12 to 18 in.).

c. Drive weight assembly. The drive weight assembly consists of a hammer, a hammer fall guide, the anvil, and any hammer-drop system.

(1) *Hammer.* The hammer is that portion of the drive weight assembly consisting of a 63.5 ± 1 kg (140 ± 2 lb) impact weight which is successively lifted and dropped to provide the energy that accomplishes the penetration and sampling. A pinweight hammer, a donut hammer, and a safety hammer have been used as the drive weight. A schematic diagram of each is given in Figure B-1. The donut hammer and the safety hammer are commercially available.

[1]References cited in this appendix are included in Appendix A.

(2) *Hammer fall guide*. The hammer fall guide is that part of the drive weight assembly which is used to guide the unimpeded fall of 760 ± 25 mm (30 ± 1.0 in.) of the hammer. Although it is desirable that the energy of the falling weight is not reduced by friction between the hammer and the hammer guide, the energy from the sliding hammer may be transmitted to the drill string at various efficiencies, depending upon the manufacturer's design. Because of this source of error, the type of equipment used should be recorded.

(3) *Anvil*. The anvil is that portion of the drive weight assembly through which the hammer energy is transmitted to the drill rods as it is impacted by the falling hammer. The hammer and anvil should be designed for steel on steel contact when the hammer is dropped.

(4) *Hammer drop system*. The hammer drop system is that portion of the drive weight assembly by which the operator accomplishes the lifting and dropping of the hammer to produce the blow. The cathead and rope system, trip system, or the semiautomatic or automatic hammer drop system may be used provided that the lifting apparatus will not cause penetration of the sampler into the formation while reengaging and lifting the hammer. Hammers used with the cathead and rope method should have an unimpeded overlift range of at least 100 mm (4 in.). A schematic diagram of an automatic trip for a donut hammer is presented in Figure B-2. For safety reasons, the use of a hammer assembly with an internal anvil (safety hammer) is encouraged.

(a) *Cathead*. The cathead is the rotating drum in the cathead and rope lift system. The operator successively tightens and loosens the rope turns around the drum to lift and drop the hammer.

(b) *Number of rope turns*. The number of turns of the rope can be determined as the total contact angle between the rope and the cathead divided by 360 deg. The contact angle begins at a point where the rope from the sheave at the top of the derrick makes contact with the cathead and ends at a point where the rope leading from the cathead to the operator's hands ceases to make contact with the cathead.

Two turns of the rope on the cathead is recommended. However, the actual number of turns of rope on the cathead is approximately 2-1/4 turns for clockwise rotation of the cathead or 1-3/4 turns for counterclockwise rotation of the cathead. Figure B-3 is a sketch of the rope wrapped on the cathead which illustrates the number of turns of the rope.

d. Drilling equipment. Drilling equipment is used to provide a suitably clean open hole in which the sampler can be inserted. The diameter of the borehole should be greater than 56 mm (2.2 in.) and less than 162 mm (6.5 in.). The selection of appropriate drilling equipment and performing the drilling operations using accepted drilling procedures help to ensure that the penetration test is conducted on undisturbed soil.

(1) *Drill rods*. The drill rods are used to transmit the downward force and torque from the drill rig to the drill bit for drilling the borehole.

(2) *Drag, chopping, or fishtail bits*. These drill bits may be used in conjunction with open-hole rotary drilling or casing-advancement drilling methods. To avoid disturbance to the underlying soil, drilling fluid must be discharged through ports on the side of the bits. Bottom discharge of the drilling fluid is not permitted.

(3) *Roller cone bits*. Roller cone bits may be used in conjunction with open-hole rotary drilling or casing-advancement drilling methods. The drilling fluid must be deflected to avoid disturbance to the underlying soil.

(4) *Hollow-stem continuous-flight augers*. Hollow-stem augers may be used with or without a center bit assembly to drill the borehole.

(5) *Solid-stem continuous-flight augers, bucket augers, and hand augers*. Solid-stem augers, bucket augers, or hand-held augers may be used if the soil on the walls of the borehole does not cave onto the sampler or sampling rods during sampling operations.

e. Sampling equipment. Sampling equipment is used to obtain a soil sample in conjunction with the SPT.

(1) *Sampling rods*. Sampling rods, which are considered to be synonymous with drill rods, are flush joint steel drilling rods that connect the drive weight assembly to the split-barrel sampler. The sampling rods should have a stiffness (moment of inertia) equal to or greater than the stiffness of an "A" rod; an "A" rod is a steel rod which has an OD of 41 mm (1-5/8 in.) and an ID of 29 mm (1-1/8 in.). Research has indicated that drill rods with stiffnesses ranging from "A" to "N" rod sizes will usually have a negligible effect on the SPT blowcount, N, values to depths of at least 30 m (100 ft). However, "N" rods which are stiffer than "A" rods are recommended for holes deeper than 15 m (50 ft).

(2) *Split-barrel sampler*. The split-barrel sampler, which is frequently called a split-spoon sampler, consists of a sampler head, a split-barrel sampling tube, and a driving shoe. A schematic drawing of a split-barrel sampler is shown in Figure B-4. Before the sampler is used, all components should be clean and free of nicks and scars made from tools and rocks. Individual components should be replaced or repaired if they become dented or distorted.

(a) *Sampler head*. The sampler head contains a number of vents of sufficient size which will permit unimpeded flow of air or water from the tube upon entry of the sample. These vents should be equipped with nonreturn valves which will provide a watertight seal when the sampler is withdrawn from the borehole. For a typical, commercially available split-spoon sampler, the sampler head contains four vent holes. Each vent hole is usually 13 mm (1/2-in.) diameter.

(b) *Split-barrel sampling tube*. The split-barrel sampling tube is made of hardened steel with smooth internal and external surfaces. Its dimensions are 51-mm (2-in.) OD by 35-mm (1-3/8-in.) ID. The minimum length of the tube is 457 mm (18 in.). It should be noted that a split-barrel sampling tube with an ID of 38 mm (1-1/2 in.) may be used provided that the tube contains a liner of 16-gauge (1.5-mm) wall thickness.

(c) *Driving shoe*. The driving shoe is heat-treated, case-hardened steel. It has an OD of 51 mm (2 in.) and an ID of 35 mm (1-3/8 in.). Its length is 76 mm (3 in.). The outside of the bottom 19 mm (3/4 in.) of the driving shoe should be tapered uniformly inward to the internal bore to form a the cutting edge.

(3) *Liners*. Liners can be used provided that a constant ID of 35 mm (1-3/8 in.) is maintained. The use of liners should be noted on the boring log or penetration record.

(4) *Sample retainers*. A variety of sample retainers may be used to prevent sample loss during the withdrawal of the sampler from the borehole. The type of sample retainer should be noted on the penetration record.

B-3. Advancing the Borehole

The borehole may be advanced using equipment and procedures that provide a suitably clean stable hole and assure that the SPT can be performed on essentially undisturbed soil. Methods of advancing the borehole which have been proven to be acceptable include wireline or open-hole rotary drilling, continuous-flight hollow-stem or solid-stem augering, and wash boring methods provided that bottom discharge bits are not used. Methods which produce unacceptable borings include jetting through an open-tube sampler followed by sampling when the desired depth is reached, using continuous-flight solid-stem augers in cohesionless deposits below the water table, drilling into a confined cohesionless stratum that is under artesian pressure, or advancing the borehole solely by means of previous sampling with the SPT sampler. The use of a bottom discharge bit is strictly prohibited.

The borehole can be advanced incrementally, alternating with testing and sampling operations. Continuous sampling of the substrata may be conducted, although this could affect the N-values; typical testing and sampling intervals are 0.6 to 1.5 m (2 to 5 ft) in homogeneous strata. Additional tests should be conducted at every change of strata. Boreholes can be stabilized using procedures which were outlined in paragraph 6-2 for undisturbed sampling operations. If drilling mud is used, the drilling fluid level in the borehole should be maintained at or above the groundwater level at all times. Drilling and sampling tools should be withdrawn slowly to prevent disturbance of the soil on the bottom and the walls of the borehole. If casing is used, the casing should not be advanced below the top of the stratum to be sampled.

The diameter of the borehole should be greater than 56 mm (2.2 in.) and less than 162 mm (6.5 in.). A smaller diameter hole may tend to close slightly and bind the drill rods, whereas a larger diameter hole may significantly alter the stresses at the bottom of the borehole. A large-diameter borehole may also allow excessive bending of the drill rods, especially for long sections of drill rod. These conditions could result in erroneous penetration resistances.

B-4. Sampling and Testing Procedure

After the boring has been advanced to the desired sampling depth or elevation and excessive cuttings have been carefully removed from the bottom of the borehole, the split-spoon sampling apparatus may be assembled and lowered into the borehole. The recommended procedures for conducting the SPT and obtaining a representative sample of soil are presented below.

As the drilling rods are connected to lower the sampler to the bottom of the borehole, inspect each sampling rod to ensure that it is straight. If the relative deflection of a particular rod is greater than approximately 1:1000, it should not be used. Precaution should be taken to ensure that each rod joint is securely tightened. When the sampling apparatus has been lowered to the bottom of the borehole, secure the drill rods and sampler by the chuck on the drill rig to prevent disturbance of the soil at the bottom of the borehole as the hammer drive weight assembly is attached to the sampling rods. Attach the hammer assembly to the top of the drill rods and carefully lower the sampler onto the soil at the bottom of the borehole. Do not allow sampler to drop onto the soil to be sampled. Rest the deadweight of the sampler, sampling rods, and hammer drive weight assembly on the bottom of the boring.

a. Seating the split-barrel sampler. Compare the depth of the bottom of the borehole to the depth of the bottom of the sampler. If the sampling spoon advances below the bottom of the borehole under the static weight of the drill rods plus the weight of the hammer, measure the penetration of the sampler into the soil and note this information on the boring log. After the initial penetration caused by the deadweight of the SPT sampling system has occurred, apply one blow of the hammer to seat the sampler. Note this depth on the boring log and drive the sampler as described in paragraph B-4*b*. If the static penetration exceeds 450 mm (18 in.), stop the test and record the blowcount as zero. Remove the rods and sampler from the boring. Advance the borehole to the next sampling depth, remove the cuttings, and lower the sampler to the bottom of the borehole to begin the next drive.

If the depth of the sampling spoon is less than the depth to which the borehole was advanced, cuttings may have settled to the bottom of the hole or the walls of the borehole may have sloughed. Note the depths of the bottom of the borehole and the sampler on the boring log. If the difference of the depths is less than 76 mm (3 in.), which is the length of the driving shoe, apply one hammer blow to the sampler. Again, compare the depths of the bottom of the borehole to the bottom of the sampler. If the sampler is seated in virgin material at the bottom of the borehole, note the depth on the boring log. If the sampling spoon is not seated in virgin material, apply an additional blow with the hammer. Again, compare the depths of the bottom of the cleaned borehole to the bottom of the sampler and note these data on the boring log. Repeat the procedure until the sampling spoon is seated in virgin material. When the bottom of the sampling spoon has been embedded in virgin material, apply one blow to seat the sampler; record this depth on the boring log, and then drive the sampler according to the procedures which are described in paragraph B-4*b*.

If the difference of the depths of the bottom of the borehole and the bottom of the sampler is greater than the length of the driving shoe, remove the sampler from the borehole. Clean the cuttings and/or slough material from the hole. Record this operation on the boring log. When the cleaning operation has been completed, lower the sampler into the borehole and compare the depth of the bottom of the sampler to the depth at the bottom of the hole. If the difference of the depths is less than 76 mm (3 in.), seat the sampler as described in the preceding paragraph. If the difference of the depths is greater than 76 mm (3 in.), remove the sampler from the boring and repeat the cleaning procedure.

After the split-barrel sampler has been seated in virgin material, mark the rods in three successive 150-mm (6-in.) increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 150-mm (6-in.) increment of penetration. It should be noted that although the penetration of the sampler through the cuttings which have settled to the bottom of the borehole is not considered to be part of the penetration resistance test, the penetration of the sampler through this material must be considered as the total penetration or drive of the sampler. Care is required to ensure that the sampler is not overdriven. Overdriving of the sampler, which occurs when the total penetration of the sampler exceeds the total inside open length of the sampler, will result in erroneous penetration resistance data.

b. Driving the sampler. To drive the sampler, the 63.5-kg (140-lb) hammer is raised 0.76 m (30 in.) above the upper face of the drivehead assembly. The hammer is then allowed to fall freely and strike the face of the drivehead assembly. The procedure is repeated to drive the sampler into the soil.

Methods for raising and dropping the hammer include the automatic, semiautomatic, and trip-hammer drop systems. The drop of the hammer should be checked to ensure that the hammer falls exactly 0.76 m (30 in.) unimpeded. The desired rate of application of hammer blows is 30 per minute (min). It is assumed for most soils that this rate of application will permit the conditions at the sampling spoon to equilibrate between successive blows of the hammer.

If the cathead and rope method of raising the hammer is employed, a number of conditions should be considered and addressed. For each hammer blow, a 0.76-m (30-in.) lift and drop should be used by the operator. Marks may be placed on the guide rod at 0.74 and 0.76 m (29 and 30 in.) to aid the operator in determining the point at which the hammer has been raised exactly 0.76 m (30 in.). The operation should be performed rhythmically without holding the rope at the top of the stroke. The desired rate of application of hammer blows is 30 per min. An excessive rate of application of blows could prevent equilibrium between blows or could result in a nonstandard drop distance. Two turns of a relatively dry, clean, and unfrayed rope should be used on the cathead. The cathead should be operated at a minimum speed of 100 revolutions per minute (rpm). It must be essentially free of rust, oil, or grease and have a diameter in the range of 150 to 250 mm (6 to 10 in.). These values should be reported in the boring log.

Count the number of blows for each 150-mm (6-in.) increment of penetration until the sampler has penetrated 450 mm (18 in.) into the soil at the bottom of the borehole or until refusal has occurred. Refusal is defined as the condition when 50 blows have been applied during any one of three 150-mm (6-in.) increments of drive, a total of 100 blows has been applied to the sampler, or when there is no observed advance of the sampler during the application of 10 successive blows of the hammer.

Record the number of blows for each 150-mm (6-in.) increment of penetration or fraction thereof. If the sampler is driven less than 0.45 m (18 in.), the number of blows for each partial increment should be recorded. For partial increments, the depth of penetration should be reported to the nearest 25 mm (1 in.). Cite the reason(s) for terminating the test.

It should be noted that the first 150 mm (6 in.) of drive is considered to be a seating drive. The sum of the blows required for the second and third 150-mm (6-in.) increments of penetration is termed the “standard penetration resistance” or the “N value.”

c. Withdrawal of the sampler from the borehole. For many drilling and sampling operations, the sampler may be withdrawn by pulling the line attached to the hammer. This action will cause the hammer to be raised against the top of the drivehead assembly and lift the entire hammer assembly, sampling rods, and split-barrel sampler from the bottom of the borehole. If this method of extracting the sampler from the bottom of the borehole is unsuccessful or the sampler is extremely difficult to withdraw, several short, light, upward strokes of the hammer will drive the sampler upward. When the sampler is free, the entire string can be withdrawn from the borehole.

B-5. Factors Which Influence Penetration Data

Recently conducted research has identified a number of factors which could affect SPT blowcount data. Although the effects of several of these factors have been investigated and SPT procedures have been standardized as a result of the studies, a number of variables have not yet been investigated and/or standardized. Because the effects of these variables may be quantitatively, and for some cases qualitatively unknown, this discussion is intended to inform the drill rig operator as well as the geotechnical engineer of potential errors or sources of errors which could affect the SPT blowcount data. If the practitioner is aware of this information, it is believed that some of the uncertainty of the use and interpretation of SPT data can be minimized.

Because of the uncertainty of the qualitative and/or quantitative effects of many of the variables which could influence the SPT blowcount data, it is recommended that standard procedures should be followed and practiced. All pertinent data with respect to test conditions and equipment should be recorded. If differences of test results are identified for “identical” site conditions during the analyses and interpretation of the data, perhaps the discrepancy or error could be explained by arguments such as the condition of the equipment, or differences of equipment, procedures, or weather conditions.

a. Schmertmann’s study. Schmertmann (1978) identified a number of factors which could influence the SPT blowcount data. These factors included penetration interval, sampling tube design, the number of turns of rope on the cathead, variations of drop height of the hammer, energy delivered to the sampling spoon, and the in situ effective stress condition. He also estimated the effects of the respective factors on the magnitude of the potential error on the SPT blowcount data. A brief discussion of the effects of these variables on SPT data is presented below.

(1) *Penetration interval.* The blowcount data should be recorded for each of three consecutive 150-mm (6-in.) increments of drive of the sampling spoon after the sampling tube has been seated in virgin material by one blow of the hammer. The SPT blowcount, N, is the sum of the number of blows for the depths of penetration from 150 to 300 mm (6 to 12 in.) and 300 to 450 mm (12 to

18 in.). Schmertmann suggested that the wrong sampling interval, such as 0 to 150 mm (0 to 6 in.) plus 150 to 300 mm (6 to 12 in.), could introduce an error of blowcounts, N, on the order of 15 to 30 percent.

(2) *Sampling tube design*. The physical dimensions of the split spoon could affect the SPT blowcount. For example, the use of a liner in the sampling tube would cause an increase of the blowcount as compared to the use of the same sampling tube without a liner. Schmertmann estimated that the use of a larger diameter sampling tube without a liner could cause a reduction of the penetration resistance on the order of 10 to 30 percent.

(3) *Number of turns of rope on the cathead*. Rope which is wrapped around the cathead may seriously impede the fall of the hammer. Consequently, the energy which is delivered to the anvil could be significantly less than the theoretical value computed for a free-fall condition. To minimize the potential differences of SPT blowcount data caused by the friction between the cathead and the rope, only two turns of the rope around the cathead should be used. It should be noted that the actual number of turns is approximately 1-3/4 for counterclockwise rotation of the cathead or 2-1/4 for clockwise rotation of the cathead. Schmertmann estimated that the error caused by friction between the rope and the cathead could increase the blowcount data by as much as 100 percent.

(4) *Variation of drop height of hammer*. With other factors constant, the energy which is delivered to the anvil by the hammer is proportional to the free-fall distance of the hammer. Therefore, care is necessary to ensure that the drop of the hammer is constant. The standard procedure specifies that the height of the drop is 76 cm (30 in.). Schmertmann estimated that the error cause by an incorrect drop distance was approximately ±10 percent.

(5) *Energy delivered to sampling spoon*. The length of the drill rods, the section modulus of the rods, and the mass of the anvil may affect the energy which is transferred to the drill rods and delivered to the sampling spoon. Schmertmann suggested that use of a large anvil as compared to a small anvil could increase the blowcount by as much as 50 percent. With respect to the length of the drill string, Schmertmann estimated that the blowcount could be 50 percent too high for short sections, i.e., less than 3 m (10 ft), of drill rods. Likewise, he estimated that an error on the order of about 10 percent could be caused by using an excessively long drill string. Schmertmann based his comparison on a section of drill rod which ranged from 9 to 24 m (30 to 80 ft) in length.

(6) *Effective stress condition*. The SPT blowcount data may be affected by the change of effective stresses in the sampling zone. The effective stress condition at the bottom of a borehole is dependent on the diameter of the borehole, the use of drilling mud as compared to casing, or the use of the hollow-stem auger as compared to casing and water. Schmertmann recommended the use of drilling mud in the borehole to minimize the change of effective stresses in the borehole.

b. ASTM guidance. The American Society for Testing and Materials (1993) published a list of factors which could effect penetration resistance in ASTM D 1586-84. It was reported that the use of faulty equipment, such as a massive or damaged anvil, a rusty cathead, a low-speed cathead, an old and/or oily rope, or massive and/or poorly lubricated rope sheaves could contribute significantly to differences of N values obtained between different operators or drill rig systems. ASTM reported that variations on the order of 100 percent or more had been observed for different apparatus or drillers for adjacent borings in the same formations. For the sake of comparison of the data, ASTM reported that for the same driller and sampling apparatus, the coefficient of variation was about 10 percent. To reduce the variability of blowcount data produced by different drill rigs and operators, ASTM suggested that the hammer energy which was delivered into the drill rods from the sampler should be measured and an adjustment of the blowcount data could be made on the basis of comparative energies.

c. Guidance by the ICSMFE. The International Committee on Soil Mechanics and Foundation Engineering International Reference Test Procedure for SPT (Decourt et al. 1988) identified several variables which could influence the SPT blowcount. Variables included unacceptable disturbance during preparation of the borehole, failure to maintain sufficient hydrostatic head in the borehole which could result in the flow of soil into the borehole, disturbance caused by overboring or overdriving of casing, the omission of liners which would reduce the penetration resistance, energy transmitted to the rods which was dependent on the shape of the hammer and the number of turns of rope on the cathead, and a large steel drivehead which could increase the penetration resistance because of a decrease of energy transmitted to the rods. Also of interest was the statement that there were "no significant differences in blowcounts or energy transferred for rods weighing 4.33 to 10.03 kg/m" (2.9 to 6.7 lb/ft). In should be noted that rods weighing 4.33 to

10.03 kg/m (2.9 to 6.7 lb/ft) compare to AX and NX rods. One other important statement was also noted: "...the energy input definition has not been proposed because of the lack of experience and the possibility of its becoming part of a 'test' routine rather than the intention solely for 'equipment' calibration...." Although this statement appears to conflict with the procedure recommended by ASTM, the decisions regarding the calibration of drilling and sampling equipment should be made by the engineer in charge following the official guidance from the Department of the Army, U.S. Army Corps of Engineers. If official guidance is unavailable, the boring logs should contain information about the hammer energy and how the energy or efficiency was obtained.

d. Studies reported by other researchers. Other researchers have identified additional factors which could influence penetration resistance. Riggs (1986) identified several factors which could affect SPT N values but were missing in ASTM D 1586-84. The factors included requirements on hammer and anvil dimensions, mass and diameter of the rope sheaves, derrick height, and alignment or configuration of the cathead and crown sheaves. Studies reported by Kovacs and Salomone (1982) indicated the number of wraps of rope on the cathead, the drop height, the drill-rig type, hammer type, and operator characteristics influenced the energy delivered to the drill stem.

B-6. Sampling Records and Preservation of Samples

After the sampler has been removed from the borehole and detached from the drill rods, the sampling spoon can be disassembled and the soil in the sampling spoon can be examined. If there is soil within the sampler, record the length of the sample recovered or the percent recovery. Describe the soil according to the instructions and procedures in Appendix E. Note the location of each stratum with respect to the bottom of the sampler barrel. Place a representative portion of each stratum into a waterproof container (jar) without ramming or distorting any apparent stratification. One or more containers may be used, as necessary. Seal each jar to prevent evaporation of soil water. Affix a sample label to each container. Include information on the label, such as project number or site, borehole number, sample number and depth, description of the soil, strata changes within sample, sampler penetration and recovery lengths, number of blows per 150 mm (6 in.) or partial increment, and date of sampling. Protect the samples from temperature extremes.

All pertinent borehole data, penetration resistance, and sample data must be recorded on a boring log data sheet similar to the data presented in Figure B-5. The depths at the top or bottom of each 150-mm (6-in.) increment of sampler penetration along with the number of blows required to effect that segment of penetration should be reported. Clear and accurate information is required for definition of the soil profile, depths of penetration of the sampler, penetration resistance, and location of the sample. Other information which may contribute to a more accurate estimate of the condition of the samples and physical properties of the in situ soil should also be noted.

The following information is presented as a checklist of data which should be recorded in the field:

- Name and location of the job.
- Names of crew.
- Type and make of drilling machine.
- Weather conditions.
- Date and time of start and finish of boring.
- Boring number and location. Give station or coordinates, if available.
- Surface elevation, if available.
- Method of advancing and cleaning the borehole.
- Method of keeping the boring open.
- Size of casing and depth of cased portion of boring, if used.
- Depth to base of casing with respect to depth of sampling.
- Equipment and method of driving sampler.
- Type of sampler. Include its length and inside diameter. Note if liners or sample retainers were used.
- Size, type, and length of sampling rods.
- Type of hammer and release mechanism or method.

- Height of free-fall of the hammer.

- Depth to bottom of borehole before test, depth of initial penetration, depth of split-barrel sampler after seating blow(s) have been applied, and depth after each 150-mm (6-in.) increment of penetration has occurred.

- Penetration resistance (blowcount data) for each 150-mm (6-in.) increment of penetration.

- Sample number/depth.

- Sample depth: top and bottom.

- Sampler penetration and recovery lengths.

- Description of soil. Include strata changes within the sample.

- Date of sampling.

- Obtain complete groundwater information. Include the groundwater level or elevation before the drilling and sampling operations begin, groundwater level or drilling fluid level at the start of each test, depth at which drilling fluid was lost or artesian water pressure was encountered, and time and date of each annotation. After the drilling and sampling operations have been completed, record the groundwater level in sands at least 30 min after boring was completed; in silts, record groundwater data after 24 hours (hr); in clays, record data after 24 hr and at a later time, if possible. If groundwater was not encountered, so indicate.

- Record pertinent observations which could assist in the interpretation of data, i.e., stability of strata, obstructions, etc.

- Record calibration results, where appropriate.

B-7. Interpretation of SPT Blowcount Data

Although the purpose of this manual is not to provide guidance for interpretation of SPT data for engineering purposes, the data in Table B-1 can be used by the inspector for describing the in situ soil conditions as determined by the SPT. These data have been referenced throughout the world and have been scrutinized by the engineering profession for one-half century. Furthermore, the data in Table B-1 are not significantly different from those data in EM 1110-1-1905, which presents the official guidance for interpretation of SPT blowcount data.

Specifically, EM 1110-1-1905 states that the SPT blowcount, N, should be normalized to an equivalent blowcount, N_{60}, which is the effective energy delivered to the drill rod at 60 percent of the theoretical free-fall energy. The blowcount correction factors are dependent upon the effective overburden pressure, the hammer release mechanism, and the type of hammer, i.e., donut or safety, etc. According to the data in EM 1110-1-1905, the rod energy factor varies from less than 0.8 to slightly greater than 1.0. It should be noted, however, that a number of researchers have reported that the measured energy delivered to the rods by SPT hammer/release systems were typically 40 to 55 percent of the theoretical free-fall energy; these lower values of energy delivered to the rods by SPT hammer/release systems explain the selection of the equivalent blowcount, N_{60}, as compared to a higher value for the energy factor, as inferred by the data in EM 1110-1-1905.

Table B-1
Soil Density or Consistency from Standard Penetration Test Data (after Terzaghi and Peck 1948)

	Cohesive Soil	
Consistency	Blows/foot (0.3048 m)	Unconfined Compressive Strength[1]
Very soft	Less than 2	Less than 25 kPa (0.25 tsf).
Soft	2 to 4	25 to 50 kPa (0.25 to 0.5 tsf)
Medium	4 to 8	50 to 100 kPa (0.5 to 1.0 tsf)
Firm	8 to 15	100 to 190 kPa (1.0 to 2.0 tsf)
Very firm	15 to 30	190 to 380 kPa (2.0 to 4.0 tsf)
Hard	Greater than 30	Greater than 380 kPa (4.0 tsf)

	Cohesionless Soil
Density	Blows/foot (0.3048 m)
Very loose	Less than 4
Loose	4 to 10
Medium dense	10 to 30
Dense	30 to 50
Very dense	Greater than 50

[1] The unconfined compressive strength may be approximated by the pocket penetrometer or the vane shear apparatus.

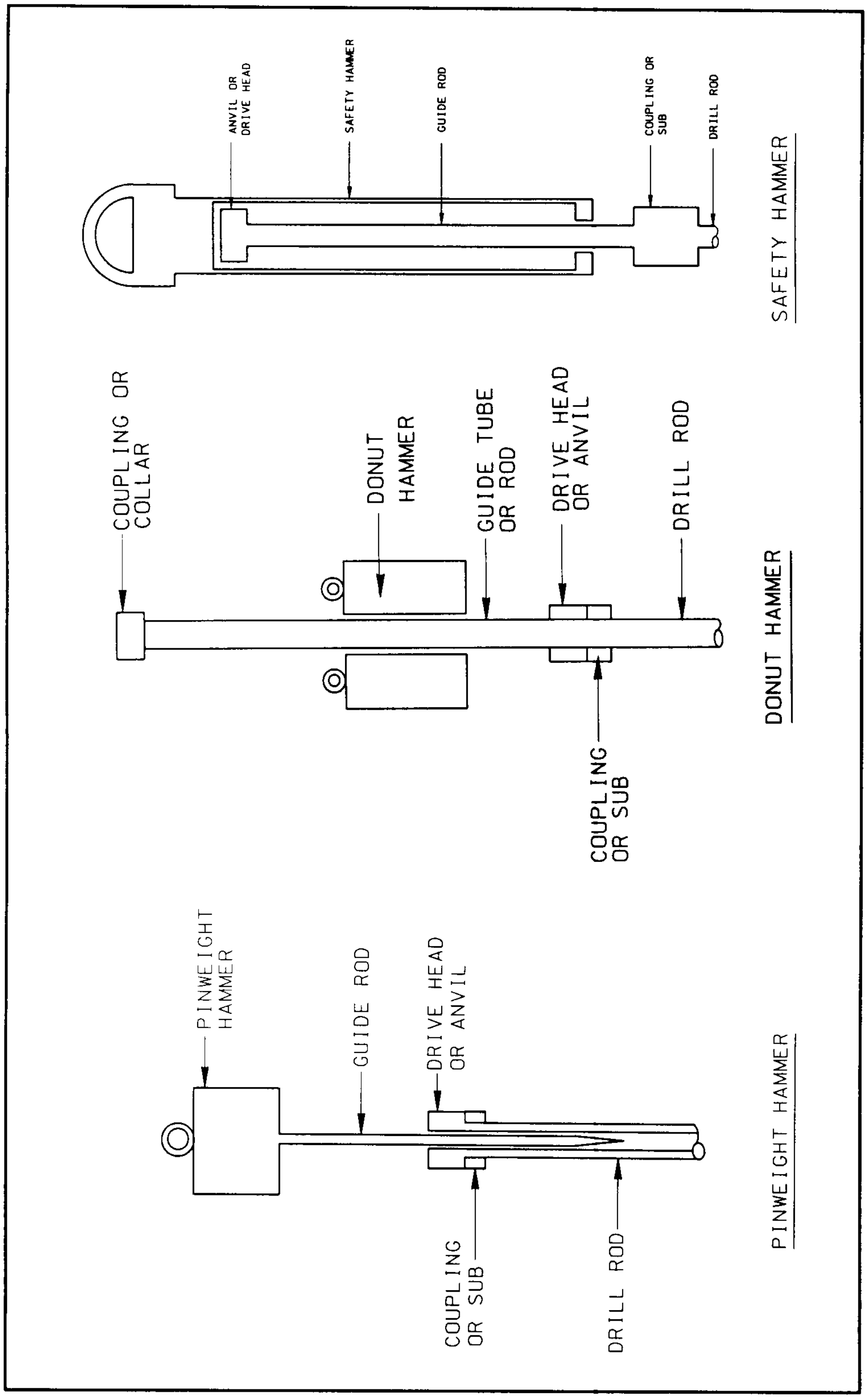

Figure B-1. Schematic drawing of the pinweight hammer, the donut hammer, and the safety hammer (after Riggs 1986)

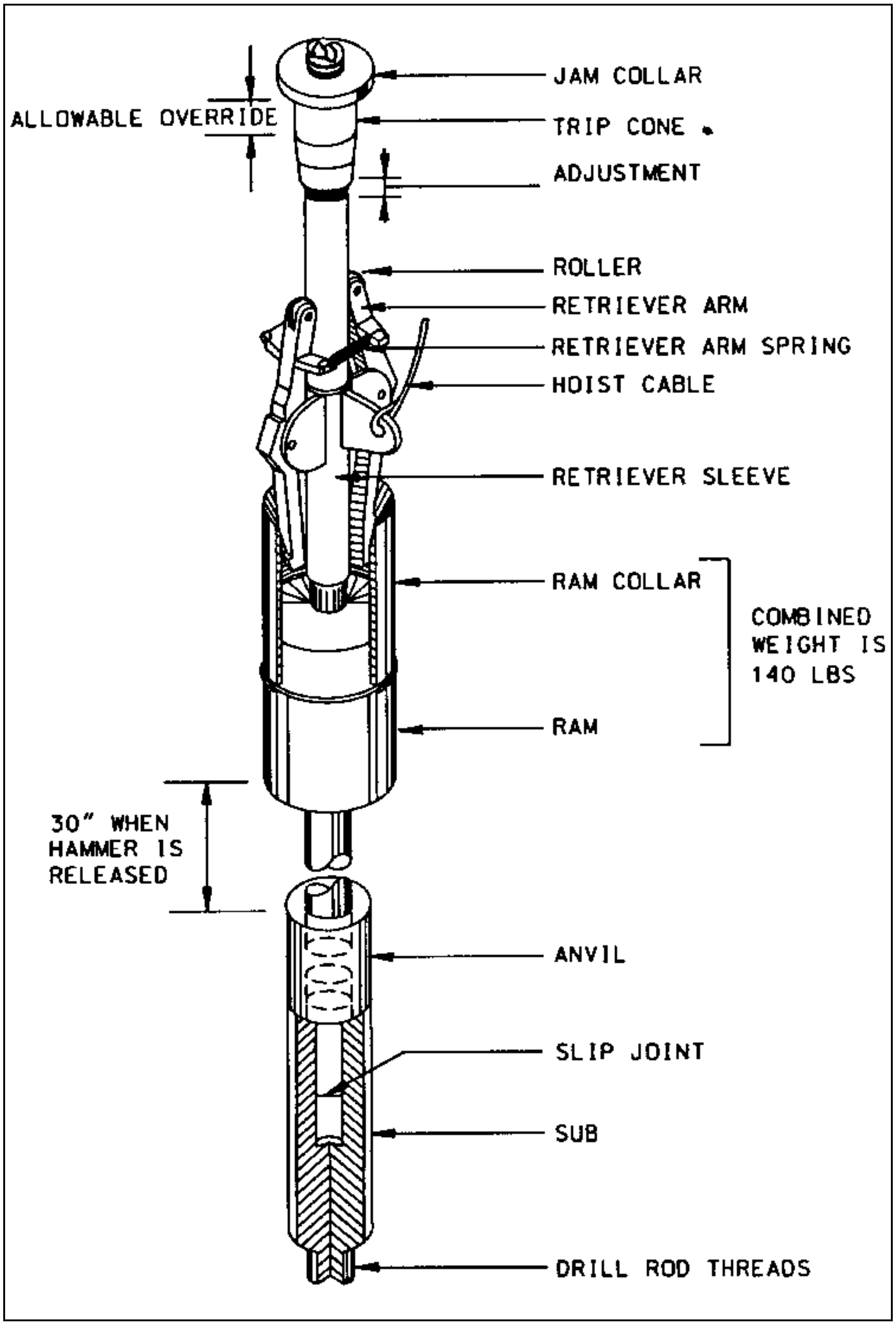

Figure B-2. Schematic drawing of the automatic trip hammer

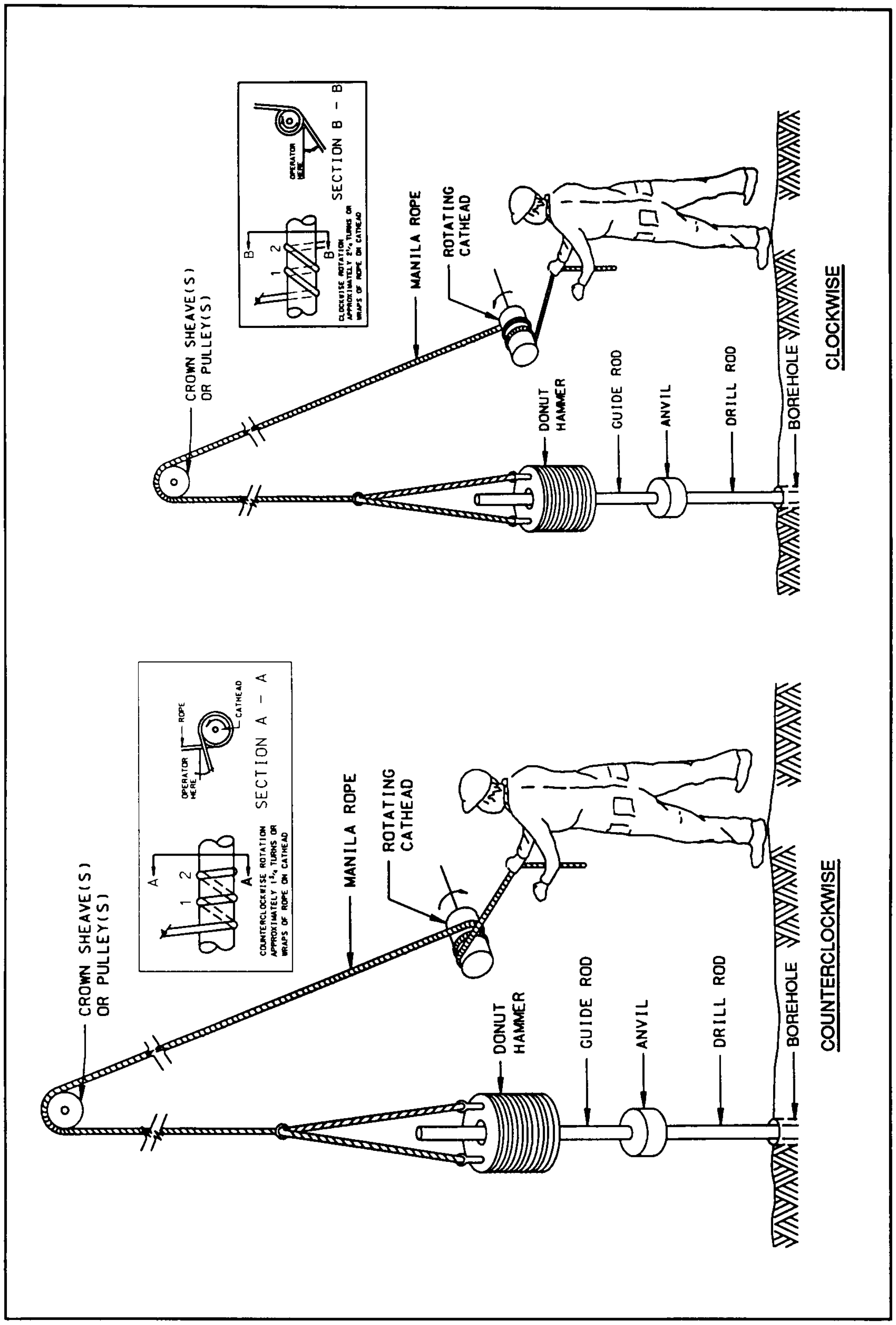

Figure B-3. Schematic drawing of the number of turns of rope on the cathead; 1-3/4 turns for counterclockwise rotation of the cathead, and 2-1/4 turns for clockwise rotation of the cathead

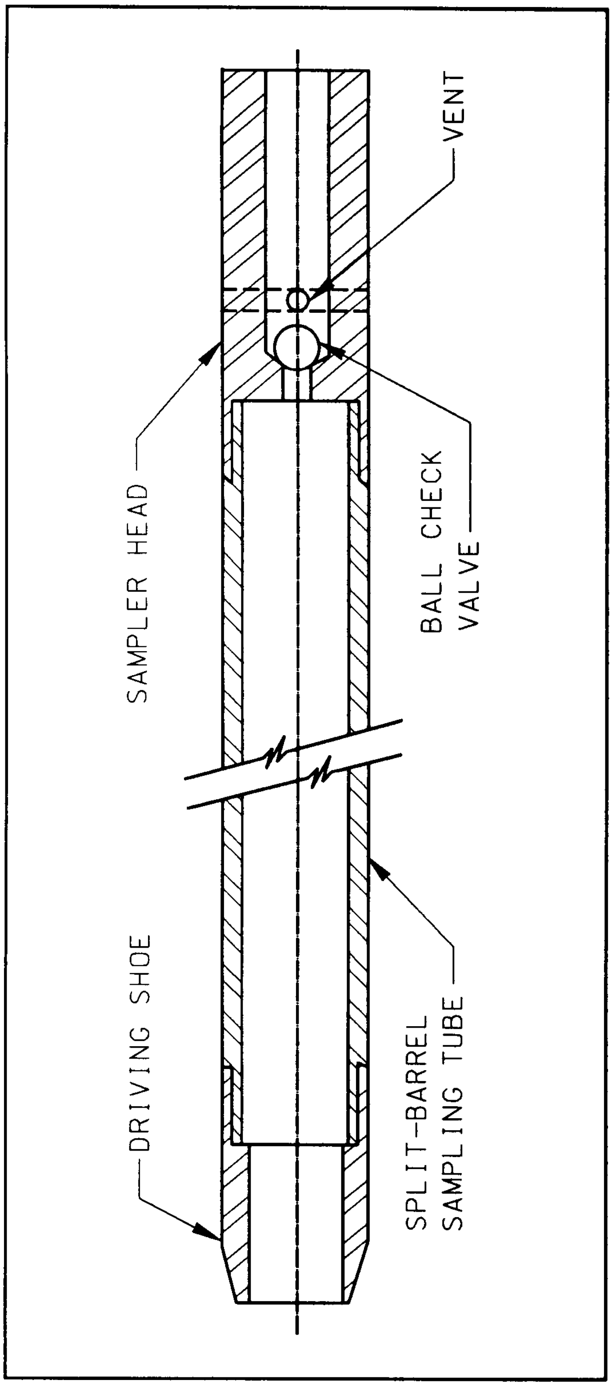

Figure B-4. Schematic drawing of the split-barrel sampler

BORING LOG
FIELD DATA

Project Morville Revetment Location Range 2, Riverside 400' Date 8 June, 1971
Drill Rig W-4048 Inspector Elliot Operator Brown Surface elev 58.0 ft. MSL
Levee District Concordia Job No. 7063 Boring No. MR-1

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER	CONTAINER	HYDRAULIC PRESSURE OR BLOWS	CLASSIFICATION AND REMARKS
—	8 June	0.0	11.5	0.0	12.0	—	—	6" Fishtail	—	—	Brown silty clay, stiff CL
1	8 June	11.5		12.0	12.5	12.4	13.2	*Splitspoon	Jar	7	Gray sand, fine SP
				12.5	13.0					10	
				13.0	13.5					15	
				13.5	14.0	—	—	4" Baffled Fishtail	—	—	Gray sand, fine SP
			14.3								
2	8 June	14.3		14.0	14.5	14.5	15.3	Splitspoon	Jar	8	Gray sand, med. SP
				14.5	15.0					10	
				15.0	15.5					16	
		Boring Complete at 15.5 Ft. depth									
* 2" OD x 1 3/8" ID x 2 ft. long splitspoon driven with 140-lb. hammer w/30" drop											

WES FORM NO. 819
REV FEB 1971

Sheet 1 of 1 Sheets

Figure B-5. Log of a penetration resistance boring with typical information which must be recorded