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Sampling Frozen Soils

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Chapter F-9
Sampling Frozen Soils

9-1. Introduction

Drilling and sampling in frozen ground is somewhat similar to performing the same operations in rock. Sellman and Brockett (1987) reported experiences of drilling in a range of geotechnical materials. For finer grained materials, such as silt, clay, organic material, and ice, at a few degrees below freezing, they reported that the materials were ductile and tough and needed to be cut like plastic or metal. They also reported that unfrozen water was sometimes present at the grain boundaries. As the in situ temperature decreased, the materials became stronger and more brittle and drilled like chemically cemented or crystalline rock. For coarser-grained frozen soils, such as coarse sands and gravels, Sellman and Brockett reported that drilling was similar to drilling in concrete. Likewise, the U.S. Army Corps of Engineers, Kansas City District (1986) reported that drillers had described drilling in frozen sand as "much like drilling sandstone."

Sellman and Brockett (1987) reported that much of the off-the-shelf drilling equipment could be used for drilling frozen soils. Diamond or tungsten drill bits with only minor modifications to the drill rig, fluid circulating system, and drilling tools could be used. However, they warned that some drill bits did not perform as well in frozen soils as in unfrozen soils. As rule of thumb, Sellman and Brockett suggested that if the bit performed well in frozen soil, it would also perform well in unfrozen soil; however, the reverse condition was not always true.

The equipment and procedures for drilling frozen soils include the use of a drill bit suited to drilling the frozen soil, equipment to chill the drilling fluid to a temperature which is equivalent to or slightly less than the temperature of the frozen formation, equipment for transport and storage of the frozen samples, and perhaps, equipment to obtain samples which are slightly larger in diameter than conventional unfrozen samples. For example, larger fluid ports in the drill bit may be needed to permit the ice cuttings to be transported without clogging the bit. If drilling fluid is used, it should be cooled to the in situ temperature to minimize the thermal shock to the formation. Lange (1963) suggested that the temperature of the drilling fluid should be within ±1 deg C (±2 deg F) of the in situ temperature of the formation. Oversized samples would permit the periphery of the sample to be trimmedprior to testing if a slight amount of thawing occurred during the sampling and handling processes. Furthermore, the larger diameter samples would be less fragile than the smaller diameter samples and therefore would be less likely to be broken during the sampling and handling processes. Related information is presented in Appendix D: "Artificial Ground Freezing for Undisturbed Sampling of Cohesionless Soils."

With respect to the strength of frozen soil, the strength would tend to increase as the temperature was decreased or as the ice content was increased. With other factors held constant, the torsional strength of a sample would increase as the diameter of the sample was increased. As compared to drilling and sampling unfrozen soils and rocks, the time required to complete each borehole would be governed by material type, equipment condition, proficiency of the operator, core retrieval efficiency, etc. Good coring practices and procedures should be followed, regardless of whether the material is sampled in a frozen or an unfrozen state.

9-2. Drilling Equipment

The principal decisions for drilling and sampling in frozen soils include the selection of suitable drilling equipment, a method of advancing and stabilizing the borehole, drilling fluid, and a refrigeration unit to cool the drilling fluid and drill string to a temperature equivalent to or slightly less than the temperature of the in situ formation. The drill bit and the refrigeration unit are probably the two pieces of equipment which will have the greatest influence on the success of drilling operations in frozen ground. A discussion of the equipment follows.

a. Drill bit. When the drill bit is selected, a number of factors regarding its design should be considered. The drill bit should be designed to resist impact loading on the cutting teeth and the abrasive action of the soil cuttings on the teeth and matrix of the bit. It should be designed for full face cutting. If a full cut design is not utilized, the uncut ribs of frozen soil will rub against the bit body and slow the drilling process. Penetration of the bit beyond the uncut ribs can be accomplished only by frictional melting and abrasion of the uncut ribs. The flow paths for the cuttings should not be obstructed. Drilling in frozen soils may cause the cuttings to stick together and refreeze. These cuttings could plug the flow paths for the drilling fluid and render it ineffective for transporting the cuttings to the surface. If an obstruction of the flow paths occurred, cuttings could collect in the annulus above the drill bit or on the walls of the borehole and cause the bit to become lodged in the borehole.

(1) *Cutting teeth.* The drilling characteristics of frozen soils vary according to grain size, ice content, and temperature of the material. In general, the material tends to become stronger and more brittle as the temperature becomes colder, although the frozen strength is usually much less than the strength of chemically cemented rock or crystalline rock. Under the action of the drill bit, the frozen material tends to crack and crumble. The characteristics of bits for drilling in frozen sediments are frequently not found in commercial bits which have been designed for use in unfrozen soils and rocks. Frequently, excessive thrust and torque are used. As a result, poor cores are produced, poor drilling rates are experienced, and excessive wear on equipment often occurs. For frozen, coarse sands and gravels, diamond drill bits have been used with limited success, provided that the matrix or ice is frozen solidly. However, diamond bits are not well suited to drilling frozen fine-grained soils and ice at a few degrees below freezing. Likewise, percussion and roller rock bits are generally ineffective. The cutter teeth on most commercially available drag bits do not cut the whole face but merely dig furrows in the frozen material. This problem occurs because there is no overbreak of the material and the drill bits have not been designed to ensure a full coverage of the surface being drilled by the cutter teeth.

Chisel-edge, wedge-shaped, finger-style cutters, such as the Hawthorne bit for drilling or sawtooth bits for coring, work well in fine-grained frozen soils, provided there is overlap of the cutting surfaces. Teeth made of tungsten carbide provide a durable cutting surface. The grade of carbon in the tungsten carbide bit should be chosen to optimize abrasion resistance and impact resistance of the cutting teeth. This finger-style cutter is advantageous because the individual fingers can be easily sharpened or rapidly replaced. When a finger-style bit is used, the shape and orientation of the cutting wedges influence the efficiency and stability of the bit. The internal angle of the wedge and the angle at which it is attached to the drill bit determine its orientation. Figure 9-1 may aid the discussion of the shape and orientation of the cutting tooth.

The rake angle, $\hat{a}_1$, is the most important angle of the cutting tooth. It is the slope of the front face of the advancing wedge and is measured from vertical. As the positive rake is increased, cutting becomes easier. If the rake angle is zero, the drill cannot penetrate the formation easily. With a negative rake, thrust and torque must be increased to advance the borehole. Additionally, a negative rake could tend to cause the drill bit or drill rods to unscrew if reverse rotation is used to free a lodged bit.

The sharpness of the cutting tooth determines the efficiency of the drill bit. A measure of the overall sharpness of the wedge is expressed as the included angle, $ß_3$. This angle is usually fixed. It must be large enough to resist breakage and hold a sharp edge. Typically, 30 to 40 deg is reasonable for drilling most hard materials.

The relief angle, $ß_2$, is the slope of the underside of the tooth. It is measured from horizontal and is automatically determined for a specific cutting tooth when the rake angle is specified. The relief angle governs the rate of penetration for any specific rotation speed.

The rake angle, $ß_1$, or the relief angle, $ß_2$, may be defined as apparent angles or as actual angles, depending on the reference criteria. Apparent angles are defined with reference to the axis of the drill and are constant, regardless of the drilling conditions. Actual angles are defined with reference to the helical penetration path. Actual angles vary with the drilling conditions, including the penetration rate, rotation speed, and the radius of the boring head.

The apparent relief angle governs the rate of penetration. When the actual relief angle is reduced to zero, i.e., the helical angle of the penetration path is equal to the apparent relief angle, the rate of penetration reaches a maximum value. Hence, the maximum penetration rate for a given bit design and a specific rotation speed can be calculated. Likewise, the minimum apparent relief angle for any position on the cutting head can be calculated if the desired penetration rate and the rotation speed are given. From a practical standpoint however, the efficiency of the cutting action near the center of the bit is relatively low because the penetration rate is high as compared to the rotation speed. Thus, the center of the bit may either be fitted with a sharp spear point that indents and reams the center of the borehole or an annulus that cores a small-diameter core. If the latter method is used, the core tends to shear when the length to diameter becomes excessive.

The cutting wedges can also be designed for a specific direction of cutting. For oblique cutting, the cutting edge aids in the lateral transport of soil cuttings. During orthogonal cutting, the cutting edge travels at right angles to the tangential travel direction. The direction of cutting is important for removal of cuttings from the face of the bit. The direction of cutting, along with the location of fluid ports, should be considered when a finger-type bit is designed or selected.

Each cutting tooth should be designed for a specific location on the bit. For example, the relief angle, rake angle, and orientation of a cutting tooth located near the center of the bit may be much different than the comparable placement of a cutting tooth located near the edge of the bit. It should also be noted that although a drill bit may be designed and/or selected for a specific drilling operation or condition, wearing on the underside of the tool by the action of the cuttings may affect the efficiency of the drill bit. Periodic inspections of the drill bit and cutting surfaces should be made, and repairs or replacement of the cutting teeth or drill bit should be made as necessary.

(2) *Stability of the drill bit*. The lack of stability can cause vibrations and shuddering of the drill string. These factors, in turn, make drilling a straight hole difficult. The stability and smooth rotation of the drill bit is influenced by a number of variables which include the symmetry of the cutter placement, the number of cutters, the stability of drive unit, and the diameter of the borehole as compared to the bit body or auger diameter. A step configuration of the cutting teeth, as illustrated in Figure 9-2, tends to stabilize the bit in the borehole as well as enhancing its cutting efficiency.

b. Augers. All of the basic drilling operations, including penetration, material removal, and wall stabilization, are satisfied when drilling with augers. Furthermore, a minimum amount of hardware and equipment is required. The principal disadvantage of an auger for drilling and sampling in frozen formations is that the ambient air temperature must be lower than -2 to -4 deg C (26 to 28 deg F). If higher air temperatures are encountered, heat from the warm air will be transferred down the stem of the auger. Furthermore, heat is created as a result of friction between the soil and auger. The effect could include thawing of the pore water and deterioration of cores and walls of the borehole.

Bucket augers or hollow-stem or solid-stem augers can be used. With bucket augers or short-flight augers, the borehole can be advanced by lowering the auger in the hole and rotating. After the bucket or auger flights are filled with cuttings, the auger is withdrawn from the borehole to remove the cuttings. The auger also must be removed from the borehole before a core can be obtained. If a continuous-flight auger is used, the cuttings are carried to the surface on the auger flights. With the hollow-stem auger, a sample can be obtained by lowering a specially designed core barrel through the hollow stem to obtain a sample of soil, rock, or ice or by using the auger to cut a core of material. Sampling through a hollow-stem auger is discussed in Chapters 5 and 6. A brief description of the U.S. Army Engineer Cold Regions Research and Engineering Laboratory (CRREL) hollow-stem coring auger (Ueda, Sellman, and Abele 1975) is discussed below.

The original coring auger, known as the CRREL 3-in. (76-mm) coring auger, was the standard tool for shallow depth coring in frozen materials for three decades. The auger consisted of a section of tubing wrapped with auger flights. A cutting shoe was affixed to one end of the hollow tube, and a drive head was attached to the other end. The overall length of the barrel with the cutting shoe and driving head attached was approximately 1.0 m (3.3 ft). The cutting shoe was equipped with two chisel-edged cutting teeth. The chisel-shaped teeth were designed with a 30-deg rake angle, a 40-deg included angle, and a 20-deg relief angle. Elevating screws which were attached to the cutting shoe were used to control the effective relief angle. Cuttings were fed onto two helical auger flights. The pitch of the auger flights was 20 cm (8 in.) and the helix angle was 30 deg. During the coring operations, the cuttings were carried upward on the auger flights and allowed to pass through holes in the hollow tube and to accumulate above the core. Cuttings were not permitted to accumulate above the drive head because of the tendency to jam the sampling apparatus in the borehole. The cuttings which had accumulated above the core wedged between the core and the barrel wall during the sampling operation; this action helped to retain the sample in the coring auger. Unfortunately, it is also believed that the material that had been wedged between the core and the walls of the tube also applied torque to the core which caused the core to break into short lengths.

The Rand auger, which replaced the CRREL coring auger, was designed to obtain a core approximately 108 mm (4-1/4 in.) in diameter by 1.4 m (4.6 ft) in length. The cutting shoe was equipped with two chisel-edged cutting teeth which were affixed onto 45-deg helical slots. The teeth were designed with a 45-deg rake angle, a 30-deg included angle, and a 15-deg relief angle. Elevating screws were used to control the effective relief angle. Cuttings were fed onto two helical-auger flights. The pitch of the flights was 20 cm (8 in.) and helix angle was 25 deg. In addition to the minor changes to the Rand auger as compared to the CRREL coring auger, the significant modifications to the coring auger need to be addressed. First, holes were no longer placed in the walls of the hollow tube. The cuttings are carried on the auger flights to the top of the drive head. For the standard Rand auger, the drive cap is not solid and some cuttings may fall into the hollow tube and onto the top of the core. However, a solid drive cap can be used, if desired. To retain the core in the sample tube, the cutting shoe was fitted with spring-loaded wedges which clamped onto the periphery of the sample after the drive was completed. This clamping action helped to shear the core from the formation and retain it in the tube as the auger was removed from the borehole. For deep coring drives, a section of solid-stem flight auger can be attached to the top of the coring auger to retain the cuttings. The addition of auger flights to the top of the coring auger helps to reduce the potential for jamming the apparatus in the borehole during retraction from a deep drive. To stabilize the drill rod on long coring runs, centering disks can be used on the drill rod at 1- to 2 m (3- to 6 ft) intervals.

c. Drilling fluids, fluid pumps, and refrigeration units.

(1) *Drilling fluids*. The circulation of drilling fluid at an acceptable temperature, adequate pressure, and rate of flow is extremely important when drilling frozen soils. If the temperature of the drilling fluid or equipment is higher than the temperature of the formation, pore ice could begin to melt. If cuttings are produced more rapidly than they are removed, they may be reground by the bit. This condition would tend to slow the drilling rate. Cuttings which are not efficiently removed from the borehole tend to stick together or to the walls of the borehole and refreeze. As a result, the drilling equipment could become lodged in the borehole.

A variety of chilled fluids have been used in the drilling of frozen soils, including diesel fuel, water-based fluids such as brine and mixtures of propylene glycol or ethylene glycol and water, and compressed air. Although a comprehensive discussion of commonly used drilling fluids for soils and rocks is presented in Chapter 4, a few comments on the use of chilled drilling fluids are needed.

(a) *Diesel fuel*. A liquid drilling fluid is more viscous than air. This characteristic tends to dampen mechanical shocks and vibrations which are caused by the action of the bit and core barrel to the core or formation. When a liquid as compared to compressed air is used as the drilling fluid, the pressure at the bottom of the borehole is not abruptly altered when drilling is ceased. Furthermore, the hydrostatic head at the bottom of the borehole is similar to the in situ condition.

Arctic-grade diesel fuel may be the best drilling fluid used to drill frozen soils, rocks, and ice. Unfortunately, diesel fuel is not an environmentally acceptable drilling fluid. Diesel fuel tends to contaminate the core. It may also change the freezing point of water in the soil pores. As a result, the pore ice in the core and the walls of the borehole may begin to deteriorate during the drilling process. Other disadvantages include: a large quantity of diesel fuel is needed; protective clothing and gloves should be used; and the potential for fire is increased.

(b) *Water-based fluids*. Water-based drilling fluids, such as mixtures of two to four percent by weight of salt to water (Hvorslev and Goode 1960) or two parts of water to one part of propylene glycol or ethylene glycol, by volume (U.S. Army Corps of Engineers, Kansas City District 1986), offer many of the same advantages and disadvantages of using diesel fuel. Water-based drilling fluids reduce the vibrations and mechanical shocks to the formation caused by the drilling operations as well as stabilize and balance the in situ stresses in the borehole. Liquid drilling fluids are much more efficient than compressed air for cooling the bit and transporting the cuttings away from the drill bit and to the ground surface. However, there is the ever present possibility that the core may be contaminated by the drilling fluid which may alter the temperature required to keep the pore water frozen. As in the case for diesel fuel, the pore ice in the core and on the walls of the boring could thaw and cause deterioration of the structure. Protective clothing, gloves, and other safety items should be worn because of the potential health concerns caused by the exposure of the skin and other organs to concentrations of salt or other chemicals in the drilling fluid.

(c) *Compressed air*. Compressed air does not exchange heat as efficiently, nor is it as effective for removing cuttings from the borehole as liquid drilling fluids. However, the use of compressed air for drilling frozen formations is environmentally more acceptable than are the other liquid drilling fluids.

When drilling frozen formations including ice-saturated fine-grained soils and ice, the requirements of chilled compressed air may be somewhat different than for drilling frozen or unfrozen coarse-grained materials. When frozen formations are drilled, the temperature and the flow rate or return velocity of the compressed air should be monitored and adjusted as necessary. The temperature of compressed air may increase because of friction as it is pumped through the drill string and returned to the surface. The temperature of the return air should be slightly lower than the temperature of the formation being drilled. The required upward annular velocity is a function of the size of the cuttings, the drill bit, and the formation and should be adjusted as necessary. For example, Lange (1973a) reported that compressed air delivered at 600 standard cubic feet per minute (scfm)[1] at 110 psi was satisfactory for drilling frozen gravel. From the data which were given in Lange's report, the upward annular velocity was calculated as 20 m/sec (4,000 ft/min). Diamond impregnated and surface-set diamond bits were used. For drilling ice, Lange (1973b) reported that an uphole velocity of 8 m/sec (1,500 ft/min) was satisfactory. Finger-type ice coring bits were used. From this information, it is apparent that there is no “cookbook” answer on the correct flow rate for drilling with air. Depending on the drilling conditions, materials, and equipment, a range of compressed air requirements could be required. It is suggested that a range of flow rates should be investigated and the optimum condition should be utilized.

(2) *Fluid pumps and air compressors*.

(a) *Fluid pumps*. A progressive cavity-type pump or a positive displacement piston pump can be used for circulating a liquid drilling fluid. Precautions should include a routine inspection of the circulation system for accumulation of cuttings. If excessive cuttings are cycled through the system or accumulate along the baffles of the mud pit, the length of travel of the mud may have to be increased to allow sufficient time for the cuttings to settle before the drilling mud is recycled. The use of desanders should also be considered.

(b) *Air compressors*. The air compressor must have adequate capacity to obtain a sufficient uphole velocity to carry the cuttings to the surface. In Chapter 4, it was reported that the effective use of air as a drilling fluid required a high volume of air to efficiently remove the cuttings from the borehole. High pressure alone would not assure a sufficient volume of air. Furthermore, excessively high air pressure could damage the formation or cause other drilling problems. An uphole velocity on the order of 20 to 25 m/sec (4,000 to 5,000 ft/min) was suggested for many drilling conditions. As a matter of precaution when frozen formations are drilled with air, a routine inspection of the core barrel and bit should be conducted for constrictions of airflow, such as frozen cuttings collecting at these orifices. A sludge barrel should also be used to collect particles which are too heavy to be lifted by the flow of compressed air or if the air pressure suddenly failed.

(3) *Refrigeration units*. During drilling operations, heat is generated by the mechanical cutting of the frozen formation. Other sources of internal and external heat energies include the ambient air temperature and the frictional heating of the drilling fluid as it is compressed and/or pumped through the drill system. To minimize the thermal disturbance of the borehole wall and core, the drilling fluid, albeit liquid or gas, must be continually cooled. This cooling can be accomplished by circulating the drilling fluid through a chiller attached parallel to the coolant system.

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[1] The *McGraw-Hill Encyclopedia of Science and Technology* (McGraw-Hill, Inc. 1992) states that standard air is 20 deg C (68 deg F), 101.3 kPa (14.7 psi), and 36 percent relative humidity; gas industries usually consider an air temperature of 15.6 deg C (60 deg F) as standard.

There are no unique designs of a refrigerator plant. Generally speaking, the design of the refrigeration system can be obtained from data from compressor manufacturers handbooks, although the assistance of an engineer or technician from a refrigeration company may enhance the cost-effectiveness of the design of the system. The requirements for the system will vary according to the specific site conditions. Factors such as the type of drilling fluid, the temperature of the subsurface material, and the ambient air temperature may affect the design of the system. The cooling capacity of the refrigerator plant should be compatible with the flow rate and pressure of drilling fluid as dictated by the drilling rig and the drilling fluid pump.

The refrigeration system generally consists of a freon compressor which is used to chill a fluid, such as ethylene glycol. The drilling fluid is circulated through a heat exchanger to cool it. If compressed air is used, the heat exchanger may be similar to the radiator on an automobile or may consist of chilling coils in a pressure vessel. If a liquid drilling fluid is used, chilled ethylene glycol may be pumped through chilling coils in the mud pit or through chilling coils in a pressure vessel. When the heat exchanger system is selected, consideration should be given to the method for defrosting the system, especially when the drilling and sampling operations are conducted in a humid environment in which the ambient temperatures are anticipated to be greater than approximately -7 deg C (20 deg F). Lange (1973b) reported that it was more difficult to defrost a liquid to compressed air heat exchanger than to defrost an air to air heat exchanger. Consequently, the type of heat exchanger and the ease of defrosting it could influence the selection of the refrigeration system and/or the drilling fluid.

d. Other equipment. Drilling in frozen formations may require other special pieces of equipment. Split-ring or basket-type core lifters will likely retain core satisfactorily for most sampling operations. For deep boreholes, a drill collar (Lange, 1973b) may be used to shift the point of tension and compression in the drill string; the use of this equipment will reduce the downward pressure on the formation. Rod stabilizers (Brockett and Lawson 1985) are useful for minimizing the potential for eccentric drilling which can cause oval boreholes or cores. Sludge barrels can be placed above the core barrel when drilling with compressed air. This equipment is useful for capturing particles which are too heavy to be lifted by air pressure; it can also be used to capture the cuttings suspended in the borehole in case the air compressor suddenly failed. Additionally, the sludge barrel would minimize the potential for cuttings falling on top of the drill bit and refreezing and/or wedging it in the borehole. It is noteworthy that a sludge barrel is often affixed to the top of an auger specifically to capture the cuttings. Lastly, it may be necessary to artificially freeze an in situ formation of cohesionless soils to obtain high quality undisturbed samples. Special equipment and recommended procedures to artificially freeze an in situ formation are discussed in Appendix D.

9-3. Drilling and Sampling in Frozen Soil and Ice

The procedures for drilling and sampling in frozen ground are similar to the procedures which are used for unfrozen ground that are reported in Chapter 6. The principal differences include selecting the drilling equipment and drilling fluids, chilling the fluid and equipment, removing the cuttings from the borehole, and providing freezers or some other suitable method for storage of the frozen core. A suggested procedure is presented in the following paragraphs.

Casing may be used to stabilize unfrozen soil or water at the earth's surface or as a casing collar in frozen soil. To set the casing in frozen soil, drill a pilot hole about 1 m (3 ft) deep with a suitable drill bit. Place a 1.5 m (5 ft) long section of casing in the borehole, drive the casing to firm frozen soil, and then remove the soil from inside the casing. After the casing has been set, place the slush pit over the borehole, align the collar of the slush pit with the casing, and place packing in the joint between the casing and the collar of the slush pit. If unfrozen soil or water are encountered, the procedures for setting casing are similar to the procedures for setting casing in frozen soil. However, the depth to stable soil, and hence the depth at which the casing must be placed, may be much greater than the depth required for frozen soil.

a. Advancing the borehole.

(1) *Augering*. The procedures for using augers to advance boreholes in frozen soil or ice are similar to those which are suggested in Chapter 6. However, as with any drilling or sampling procedures, the driller may modify the recommended procedures as required to enhance the drilling and sampling operations for the particular site conditions.

(2) *Rotary drilling*. Rotary drilling in frozen soils is not much different from the procedures and operations which are reported in Chapters 6 and 8 for drilling unfrozen soils. In addition to the requirement for keeping the formation frozen by using chilled drilling fluid and drilling equipment, the primary differences for drilling in frozen soils as compared to unfrozen soils include the use of a slush pit with more baffles to allow sufficient time for the cuttings to settle, additives to adjust the viscosity and specific gravity of drilling fluid, and in some cases, the use of casing for near surface conditions when peat or large volumes of unfrozen water are encountered. Other factors which must be considered include the ambient air temperature and the weather conditions, the in situ formation temperatures, and the effects of thawing on the behavior of the material.

In general, rapid penetration at high rates of revolution of the bit with low pressures and low volumes of fluid circulation is recommended for most soils. Experience has shown that slower rates of penetration have resulted in increased erosion and thawing of the walls of the borehole because of the drilling fluid. The type of drilling fluid also needs careful consideration. Chilled air cannot remove frictional heat from the drill bit as efficiently as liquid drilling fluids. Chilled brine, ethylene glycol, or diesel fuel may be environmentally unacceptable. These drilling fluids may also change the freezing point of water in the soil pores and thus cause thawing of the formation. When casing is needed, the liquid drilling fluids may be undesirable because of the need to freeze the zone between the casing and soil.

Finger-type tungsten drag bits have been used for advancing boreholes in frozen formations. In general, the results were good except the cuttings tended to collect in the borehole and thus inhibited the cooling effects of the drilling fluid. Ice-rich silt and ice-rich sand were easily drilled and cored, although sand tended to dull the cutting surfaces more rapidly than silt. Ice-poor sand was easier to core than ice-poor silt or ice-poor clay. Dry frozen silt or silty clay was fairly difficult to drill as the cuttings tended to ball and refreeze on the walls of the borehole. The result was sticking and freezing of the bit or core barrel when its rotation was stopped. Gravelly soils tend ed to damage the carbide cutting tips. When ice formations are drilled, the downward pressure of the drill bit must be minimized. The reduction of pressure on the drill bit can be accomplished by the use of a drill collar which shifts the point of tension and compression in the drill string.

b. Sampling.

(1) *Sampling with Augers*. If sampling is conducted in conjunction with augering, the procedures will be dictated by the type of samples to be obtained. Disturbed samples cannot be obtained from the cuttings which have been carried to the surface by the auger flights; these cuttings may be mixed with materials from various depths and therefore may not be representative of the formation(s) of interest. Cores of frozen material can be obtained by the hollow-stem auger sampler, as described in paragraphs

5-1*c* and 6-4*c*, or the center bit can be removed and the barrel of the hollow-stem auger can be used as casing for sampling with core barrel samplers. It should be noted that the hollow-stem auger could freeze in the borehole during the sampling operations. Therefore, this method should be used cautiously.

The coring run consists of augering the barrel into the formation until it is filled with cuttings and core. During this operation, the depth of penetration should be monitored as an excessive drive will damage the core. However, it has been reported that when ice is cored, cuttings were purposely wedged between the core and core barrel. This action enhanced the breaking of the ice core at its base and recovering the sample. This procedure is not recommended for soil sampling operations.

Several precautions for sample coring with augers are offered. All trips up and down the borehole should be made without rotation. Select the proper bit for the formation to be drilled. Bits which are improperly matched with the formation may result in coarse cuttings which would tend to collect on the top of the core barrel. During withdrawal, the cuttings would compact and could cause the device to jam in the borehole. If the device becomes frozen in the borehole, the freezing point of the pore water in the cuttings must be lowered to free the apparatus. Cuttings can be thawed by brine solutions, antifreeze solutions, or jetting air past the cuttings. However, these operations may also cause the walls of the borehole to thaw.

(2) *Sampling with core barrel samplers*. The equipment and procedures for sampling frozen soils are similar to the equipment and operations which are reported in Chapters 5 through 8 for sampling unfrozen soils. Standard double-tube core barrels equipped with tungsten coring bits and basket-type or split-ring core lifters have been used for sampling frozen cohesive and cohesionless soils.

9-4. Special Considerations

A number of considerations are noteworthy when drilling operations are conducted in frozen formations. However, the two most important considerations are the selection of the drilling fluid and the drill bit. A brief discussion follows.

The type of drilling fluid should be selected after the benefits and limitations of each are considered. At high ambient temperatures, compressed air will not cool the drilling equipment sufficiently. As a result, the in situ formations may tend to thaw. At ambient temperatures less than about -4 deg C (25 deg F), compressed air works well although the defrosting problems for chilling air by mechanical refrigeration is difficult. Liquid drilling fluids, such as diesel fuel, ethylene glycol, and brines, have a greater capacity for heat exchange than compressed air. However, these fluids may tend to alter the freezing point of the in situ material as well as contaminate the formation and the sample cores. Furthermore, the liquid drilling fluids may have an adverse effect on the drilling equipment, i.e., the salt in a brine tends to deteriorate drilling equipment, or diesel fuel may dissolve or dilute the grease used to lubricate the drilling equipment.

The drill bits and rate of advancement should be selected according to the material in the formation. The drill bit should employ full-face cutting of the formation. Uncut ribs rub against the bit body and slow drilling and/or stop penetration. If the cutting surfaces of the bit are incorrectly positioned, an irregular and scored surface of the core may result. If the rate of penetration is too aggressive, the core may break or the fluid ports in the drill bit or core barrel may become clogged frequently. If the rate of drilling is too slow or if the cutting of the bit is ineffective, small chips or frictional melting and refreezing of the core could occur. The stability and smooth running of the drill bit is influenced by symmetry of cutter placement, the number of cutters, the stability of drive unit, and the diameter of the borehole as compared to the bit body or auger diameter. The lack of stability can cause vibrations and shuddering of the drill string which would make the drilling of straight holes difficult to impossible.

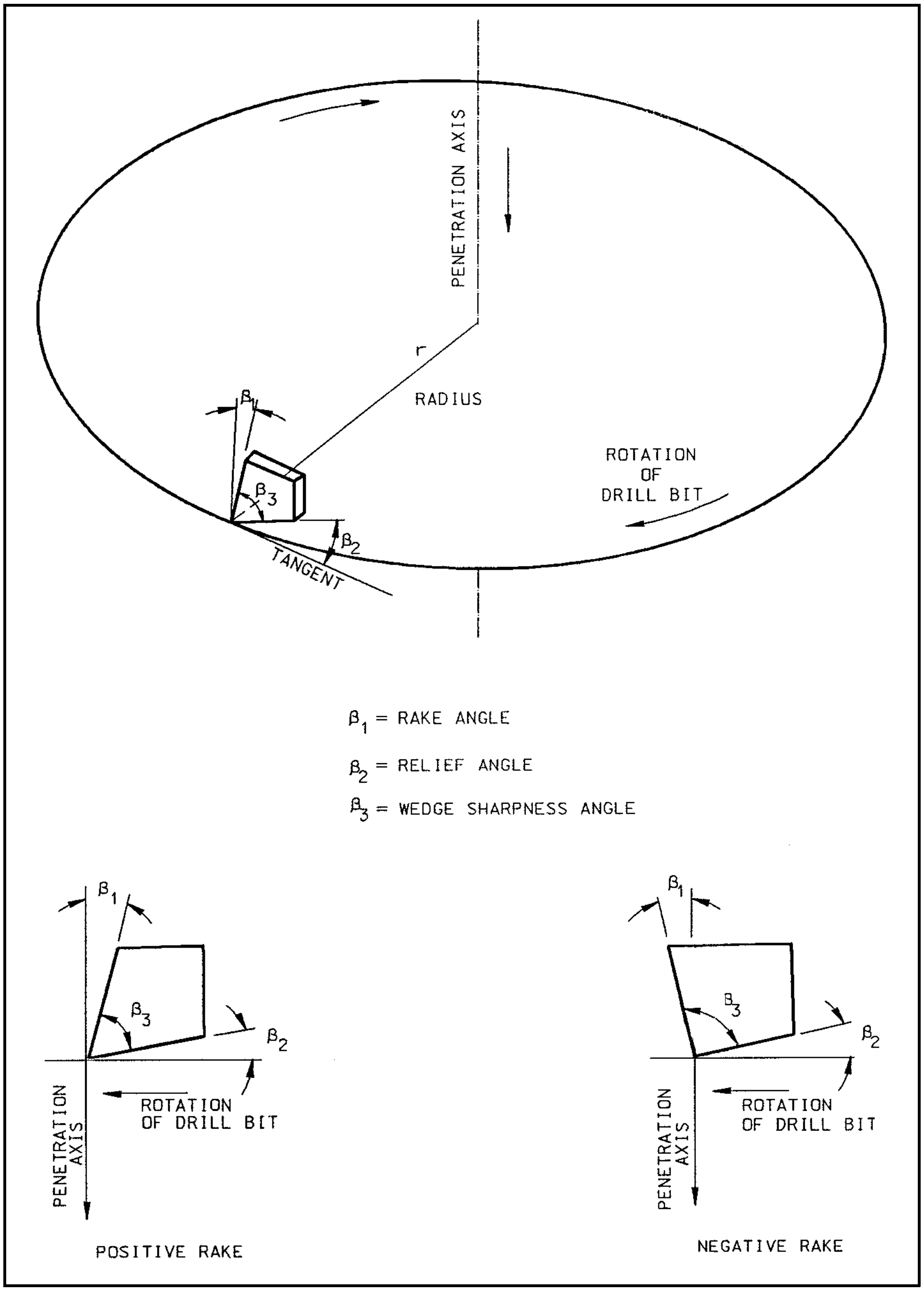

Figure 9-1. Schematic of a cutting tooth which defines the shape and orientation of the tooth (after Mellor 1976)

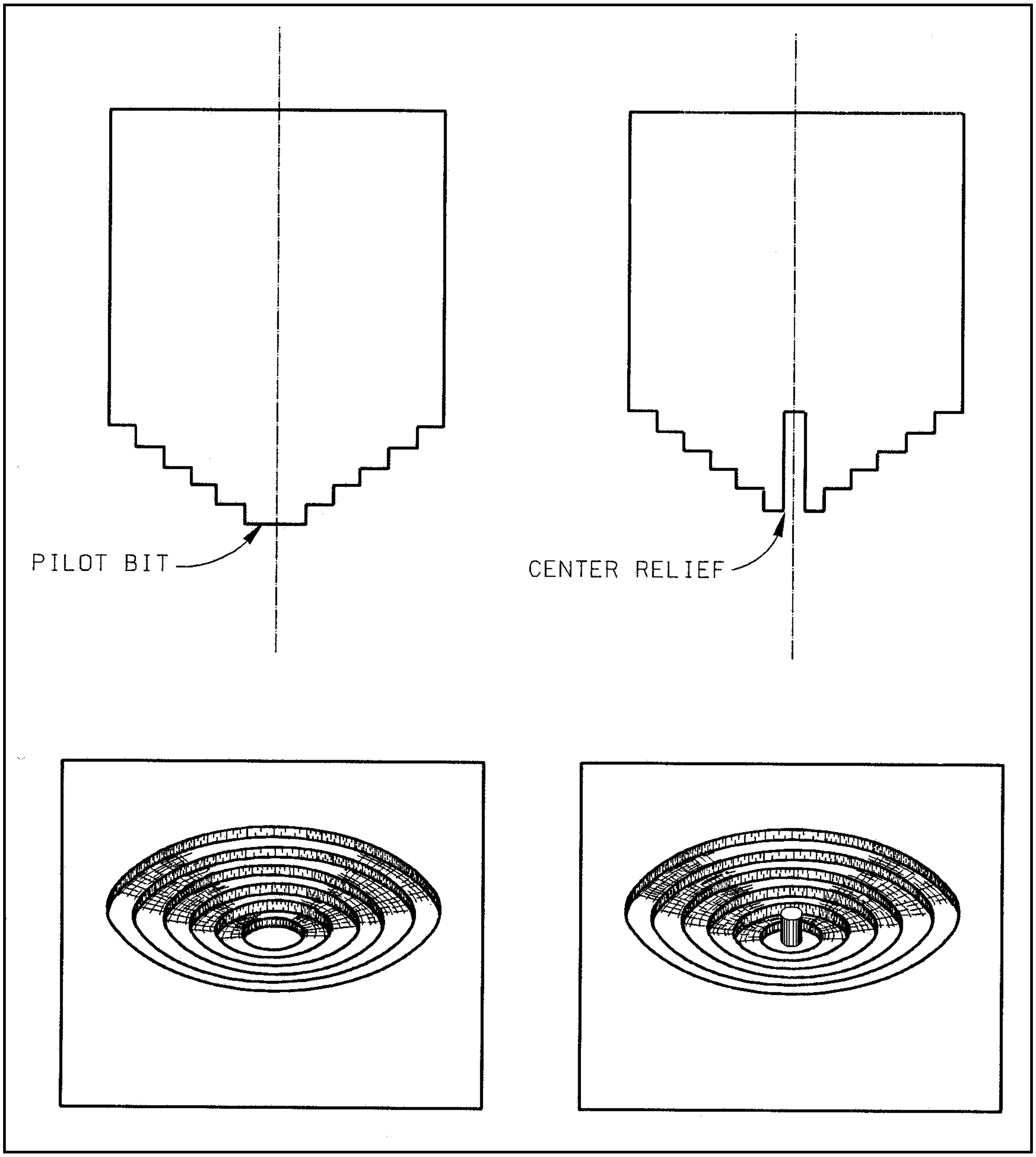

Figure 9-2. Schematic of the step configuration of the cutting teeth on a drill bit and an isometric drawing of the cut surface at the bottom of the borehole