## PDHonline Course C330 (3 PDH)

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# Sampling Frozen Soils

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This eventually produces a "wear flat" behind the cutting edge of the tool (Fig. 9c). Once a wear flat of this kind has been ground on the relief surface of the tool, it becomes more difficult to operate the bit in accordance with its design characteristics, since it no longer has an adequate primary relief angle. In fact, the wear flat can sometimes give a slight negative relief angle.

We have made simple tests that suggest a more straightforward way to determine rake and relief angles. When a hand chisel is used to groove the surface of rock, concrete, frozen soil, ice, and suchlike materials, there is a definite angle of inclination which directs the resultant of the cutting forces along the axis of the chisel. At shallower angles of inclination the chisel rides up out of the work unless a high moment is applied. At steeper angles the chisel digs in too deeply and does not travel parallel to the surface. For frozen silt, the optimum angle appears to be around 48° inclination from the work surface. Following this idea, the optimum angle of the tool's bisector is first decided; the relief angle is this inclination minus the half-angle of the wedge, and the rake angle is the complement of the inclination minus the half-angle of the wedge.

## Flow paths for chip clearing

Frozen soil cuttings tend to stick together and occasionally freeze together, particularly in silt- and clay-rich soil. This tendency is accentuated when chips are packed close together, when frozen materials are only slightly below freezing, and when tools or circulation fluids are warm. To avoid accumulation and jamming of chips in a drill bit, there has to be smooth and unimpeded flow of chips from the cutting edge to the pickup point for the transport mechanism. If flow paths are constricted or obstructed, or if the bit produces chips faster than it can transport them away, blockages will develop. Blockages can grow until the entire bit is clogged with tightly packed cuttings. The cutting head then becomes a smooth blob that is incapable of further penetration, even when driven by very large drilling rigs. Packing of cuttings between the auger flights and the hole wall can cause the drill string to stick in the ground. When this is accompanied by freezing it can make removal of the drill string difficult to impossible.

Design deficiencies on bits and boring heads can include the following: (1) failure to provide clear transport paths from all cutting edges

(2) inadequate cross-sectional area somewhere in the flow paths

(3) abrupt turns in flow paths

(4) steps or shoulders in flow paths

(5) obstacles such as bolts or locking lugs projecting into the flow path from the bit, stem or flight

(6) helical paths that are too steep

(7) inadequate flushing in fluid circulation systems (poor positioning, distribution and orientation of fluid ports)

Careful design is particularly important for auger drills, which have to rely entirely on "shoveling" and screw transport (Mellor 1981), with the same rotation speed for the cutting and clearing functions. Some problems are easy to identify on the basis of common sense and physical intuition, but impressions and deductions can be checked by testing in a sticky material, such as moist unfrozen clayey silt. Debris accumulates in front of, or in the lee of, definite obstacles. If the bit is painted and then run in more abrasive material (sandy silt), paint tends to rub off in tight spots and other problem areas.

Flow path requirements can be analyzed to some extent, as can be seen from the following simple example.

If an auger bit is to avoid jamming, the clearing paths must be able to transport chips faster than the cutters can produce them, without totally filling the area between the flights (Mellor 1976). A full-face bit of diameter D, with axial penetration rate U, excavates material from the solid at a volumetric rate of $(\pi/4)\ D^2U$. The chips occupy greater volume, and a bulking factor of 1.85 has been used when the chips are simply piled up and at rest. For an agitated mass of traveling cuttings, a bulking factor of 2 seems reasonable. Thus the volumetric flow rate for loose chips traveling through the bit is approximately $\pi D^2U/2$, which does not include spillback. For a coring auger, the corresponding production rate for cuttings is $\pi(D^2 - D_c^2)/4$, where $D_c$ is the core diameter.

When auger flights are conveying near full capacity, the vertical speed of the cuttings, $U_a$, is approximately

$$U_a \approx \pi Df \tan\alpha \approx Pf$$

where D is the outside diameter of the flight, $\alpha$ is its outside helix angle, P is the pitch, and f is the rotation speed. If the A is the horizontal cross-sectional area of the annular space occupied by the flights, then jamming can be avoided by having

$$A \geq \frac{D}{2\tan\alpha} \cdot \frac{U}{f}$$

or

$$A \geq \frac{\pi}{2} \frac{D^2}{P} \cdot \frac{U}{f} \quad .$$

The area A is

$$A = \frac{\pi}{4} (D^2 - d^2)$$

where d is the inner diameter of the flights (stem diameter).

U/f is the axial penetration per revolution; an increase in its value tends to increase the chance of jamming, but if U/. is too low, the cutters will not work properly. Within limits, an increase in the pitch of the flights, or an increase of α, will tend to lower the chances of jamming, but other problems arise if α is much above 30°. The condition for free flow of cuttings has to be met for all flow paths, and for all points on each flow path.

When fluid circulation is used, the processes of cutting and chip clearing are essentially independent and, in principle, chips can always be cleared fast enough to keep the bit free of cuttings. In practice, there are various factors that can reduce the effectiveness of the fluid stream, allowing local accumulation of chips. Potential problems include:

(1) inadequate fluid velocity (insufficient flow rate for the size of bit and/or drill stem annulus)

(2) poor location of discharge ports, leaving "dead zones" that are not swept by high velocity fluid

(3) unsuitable orientation of discharge ports, giving inappropriate flow directions

(4) constrictions or sharp bends in flow paths for the fluid/chip stream

(5) warm circulation fluids that can heat bit surfaces and tend to melt ice-rich chips

(6) ineffective cutting by the bit, leading to very small chips and excessive frictional heating (e.g. blunt cutters, or rotation speed too high for the prevailing penetration rate)

Keeping these things in mind, it is usually possible to diagnose problems and develop solutions. Expedient solutions might include such things as:

(1) bigger pump or compressor

(2) enlargement of discharge ports, drilling of extra ports and/or grinding of exit channels

(3) grinding the bit to remove flow constrictions or smooth out direction changes

(4) increasing fluid flow by reducing the number of required flow passages

(5) cooling the circulation fluid, if necessary by heat exchange in winter or refrigeration in summer

(6) producing relatively coarse chips by proper choice of bit, good maintenance of bit, and appropriate combination of rotation speed and penetration rate

Figure 10 shows an internal-discharge coring bit that was built for use with air circulation in fine-grained frozen soil. It was successful because its enlarged passages channel maximum flow across the entire cutting face. A similar bit with bottom discharge was unsuccessful, presumably because the small central ports did not give optimum streaming of the circulation fluid.

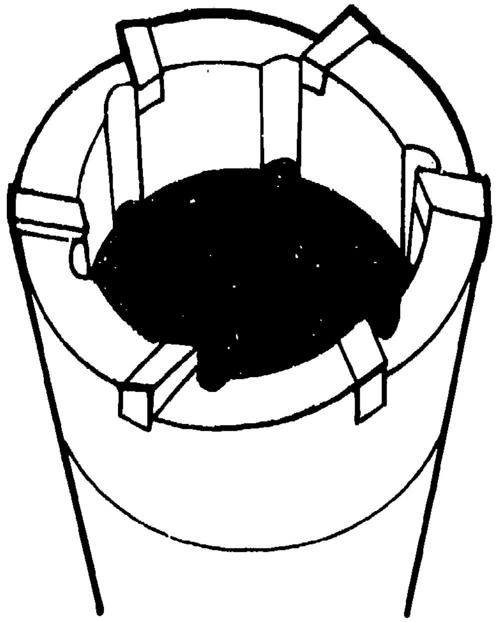

Figure 10. A saw-tooth bit with internal discharge made at CRREL. The bit has tungsten carbide tips. This combination proved successful in coring frozen sediment.

Field experience suggests that, when using compressed air, coring bits that have fewer cutters (5 to 6, compared with 8 to 10) are less likely to be blocked, at least at the flow rates available with typical equipment. With fewer cutters, chip size is increased for a given combination of rotation speed and penetration rate. The location of discharge ports on the bit is very critical if all cutter areas are to be flushed properly.

### Stability in the hole

The stability and smooth running of a drill can be influenced by a number of factors, including symmetry of cutter placement, number of cutters, stability of the drive unit, and hole size compared to bit body diameter or auger diameter.

Stability problems are probably most noticeable on auger drills that are hand-held; the operator experiences excessive lateral shuddering motion with an unstable bit. Lateral motion tends to increase the hole size, since cutters are often set with some overhang and this permits scouring of the hole wall. There is then a tendency to produce a hole that cannot be contacted by stabilizing elements. If lateral motion occurs, it can usually be restricted by: (1) reducing external overhang of cutters, (2) balancing the forces by assuring that cutters have similar distribution and the same depth of cut on opposing wings*, (3) using bit designs that include pilots and step configurations, (4) providing bit shoulders for hole wall contact, (5) assuring hole wall contact by drill string stabilizers or auger flighting. If the shoulder area of a bit is increased to improve hole wall contact, it should not compromise cutting transport, since increased shoulder area can reduce the size of flow paths for cuttings.

Precise holes with little variation in diameter can be produced with auger drills. This can be achieved by machining all components of the drill bit and the auger flighting to the same diameter and allowing only slight overhang of the cutters. Precisely drilled holes are sometimes called for when small-diameter geotechnical devices have to be installed, usually at relatively shallow depth. In more routine drilling and sampling, a drill system with a uniform OD would cause some problems, since eventual wear of the cutter head would produce an undersized hole for the rest of the drill.

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*Systematic procedures for balancing forces are discussed in Mellor (1976).

## Examples of frozen ground bits and drills

Several drills have been modified and constructed at CRREL for use in frozen fine-grained soil. Most of these were for research and engineering applications, such as making shallow, small-diameter holes for instrumentation and for obtaining undisturbed core samples within 10 m of the ground surface. Others have been developed and utilized by drilling and engineering firms. Also, some commercial bits originally intended for use in soft rock and dense soil have been used with little or no modification.

These drills can be grouped into several categories on the basis of size and application, e.g. small-diameter drills, large-hole drills, coring augers (including hollow stem drills), and rotary coring tools (requiring circulation). Examples of some of these tools are illustrated in the Appendix.

## Conclusions

The performance of drills intended for use in frozen fine-grained soil can be improved significantly by incorporation of some specific drill bit design features. Optimum design and efficiency of operation are extremely important when bits are to be used with drilling units that are hand-held, low-powered, or lightweight. These things are also important in coring operations, where minimum disturbance of the core is a requirement. Selection of an inappropriate or poorly designed bit can make penetration almost impossible, even with very large drills that have high torque and thrust capability. A bit that does not cut the material has to penetrate by abrasion and frictional melting.

The ductile nature of warm frozen silt requires that bits be constructed to cut the entire surface or face of the hole. This is necessary because very little overbreak occurs in these materials, and ribs of uncut material tend to prevent penetration by rubbing on non-cutting parts of the bit. Sharp but durable tungsten carbide cutters are necessary; they have to stay sharp as long as possible, and they have to resist damage from impact with any coarse-grained material encountered during drilling.

Bit clearance angles must be large enough to allow penetration at the maximum feasible design rates. Lack of adequate clearance angles is a common problem. Best performance is achieved when cutters have a positive rake angle. A step configuration is advantageous, since it improves cutting efficiency and stabilizes the bit in the hole. Cuttings must be able to flow freely away from the bit in smooth, open flow paths that are free of obstructions.

Bits that successfully embody the above characteristics work well and can provide very impressive performance, even with lightweight drills that have limited torque and thrust, assuming adequate consideration has been given to transport of the cuttings away from the bit.

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# APPENDIX A. EXAMPLES OF FROZEN GROUND BITS AND DRILLS

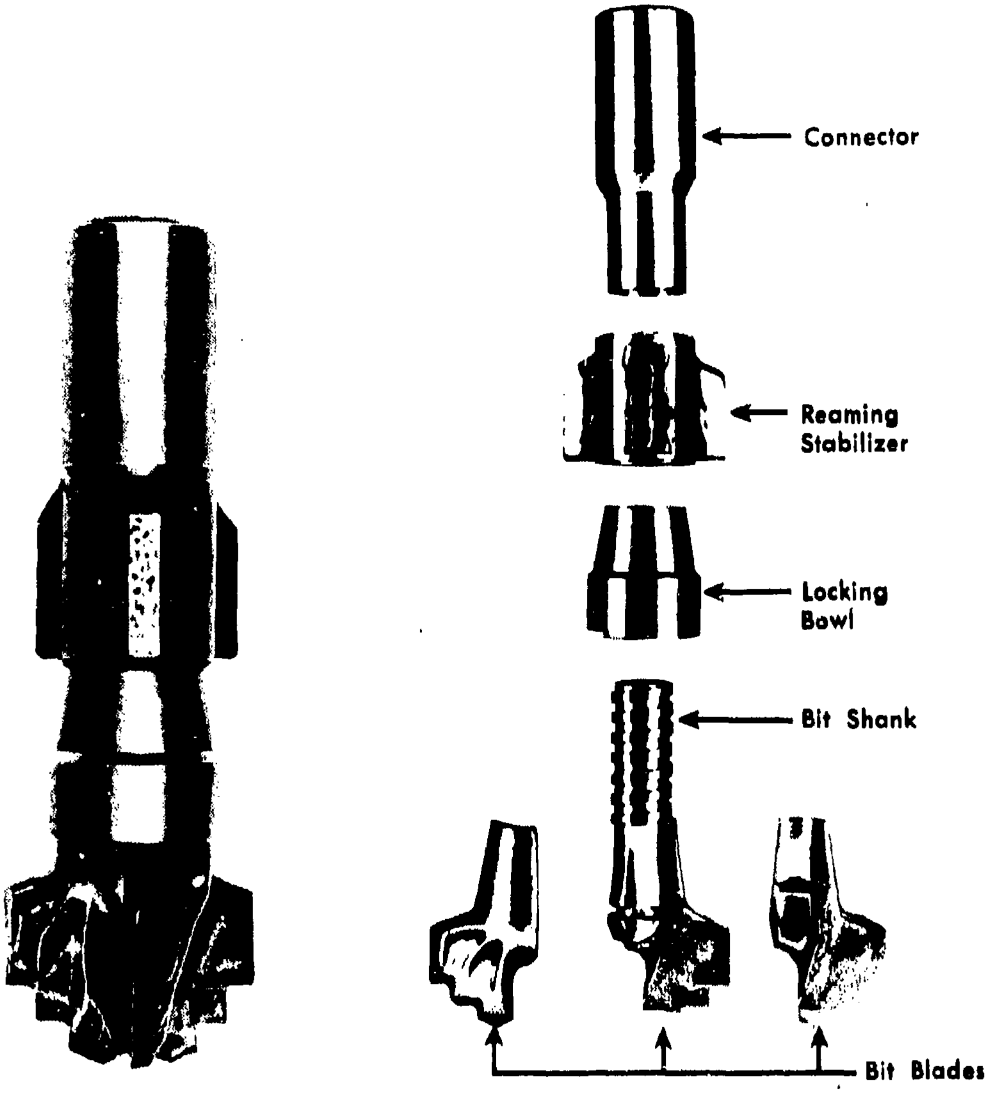

Figure A1. A commercial bit that has found direct application in frozen fine-grained soil is the old Hawthorne Blue Demon bit. This style of bit is now marketed by several companies. It has been used for many years in Alaska, including the period of early oil exploration on the North Slope, commonly with compressed air circulation for seismic shot-hole drilling in permafrost. It has replaceable blades that are hard-faced or armored with tungsten carbide cutting surfaces. The hard-faced bit has good self-sharpening characteristics and has been used in frozen fine-grained soils. These bits range in size from 1-7/8 in. (47.6 mm) to 16 in. (0.4 m). A bit of this type with carbide cutters used in ice-rich frozen silt near Fairbanks, Alaska, with chilled compressed air for circulation, produced 660 ft (200 m) of hole with little apparent reduction in performance. The last test hole, 60 ft (21 m) deep, was completed in a total of 20 minutes drilling time (Delaney, in press). (Illustrations courtesy of Hughes Tool Co., Houston, Texas.)