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Auger bit for frozen fine-grained soil

Paul V. Sellmann and Bruce E. Brockett

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PREFACE

This report was prepared by Paul V. Sellmann, Geologist, Geotechnical Research Branch, Experimental Engineering Division, and Bruce Brockett, Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The research was produced under DA Project 4A76273OAT42, Design, Construction and Operations Technology for Cold Regions, Task No. CS, Work Unit O35, Drilling Technology for Cold Regions. This is one of a series of informal reports that deal with drill design, drill fabrication and methods for drilling and sampling in ice and frozen ground.

The authors are grateful to Dr. Malcolm Mellor and Herbert Ueda for reviewing this report. They also acknowledge Dr. Richard Berg and the crew in the FERF for providing and preparing an area for the drilling tests.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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AUGER BIT FOR FROZEN FINE-GRAINED SOIL

P.V. Sellmann and B.E. Brockett

INTRODUCTION

Both commercial and military requirements exist for drilling in frozen soils. There is a strong incentive to use augering techniques since a minimum amount of equipment is required. Frozen soils, particularly rocky soils, represent the upper end of augering capability. Other drilling techniques, such as rotary and percussive, usually take over in these materials.

Even though frozen soils have been drilled and sampled for many years, drilling remains difficult because of the special properties of these materials. Frozen soils are very strong, but they are often ductile and they tend to produce cuttings that compact and cohere. The cutting characteristics often prevent the use of equipment and techniques normally used in materials having high strength (Mellor and Sellmann 1975, Sellmann and Mellor 1986). Drilling in frozen soils is often done with systems that are more complex than augering and that require fluid circulation for removing cuttings.

Extensive drilling in a range of frozen soil types was done during construction of the Alaska pipeline. The equipment produced holes up to 22 in. (559 mm) in diameter at rates as high as 2 ft/min (0.6 m/min) using a variety of techniques including augering, rotary drilling and percussive methods (Sellmann and Mellor 1978). The augering equipment was usually used in the frozen fine-grained soils that had a low rock content. Small auger bits (1-3 in., or 25.4-76.2 mm) have also been used for sampling and producing holes for instrumentation. These small drills have produced impressive rates of several feet per minute in ice-rich silty soils (Sellmann and Mellor 1986).

Military engineers need to make small-diameter holes in frozen ground for setting anchors, grounding rods and well points, and they need to make

holes of larger diameter for emplacing cratering charges. Successful drilling depends on the availability of an efficient bit, since military drills typically have less torque and thrust than the construction augers and drills commonly used for drilling in frozen ground.

We examined product literature to find a bit that conformed or was close to our specifications. A winged drag bit was selected and modified for testing at CRREL in two frozen fine-grained soil types.

APPROACH

Our approach and criteria for bit selection and design were based on experience with design, construction, evaluation and use of a range of rotary drilling, augering and coring equipment for lightweight drive systems. We hoped that a commercial auger bit could be used directly for this task. Our review of product literature yielded only one bit that appeared to have most of the features we consider important (Sellmann and Mellor 1986). These features include:

- Full face cutting. All of the advancing hole face must be cut, because uncut ribs can rub against the bit body, slowing and even stopping penetration.
- Unobstructed flow paths for cuttings. This is necessary to prevent clogging of the bit.
- Proper cutting angles and bit shape. Adequate relief angles are required, and positive rake is also a benefit.
- Durable and sharp cutters.
- Balanced bit design. This is important for stability in the hole because it reduces vibration and lateral motion.

Winged drag bits with carbide cutters were ordered in the 6.5 in. (165-mm) and 9.5-in. (241-mm) sizes. After inspection it was apparent that these bits would need modification. The cutter angles needed improvement, along with a little streamlining of the cutting flow paths. The modifications varied from "quick fixes," involving hand grinding and changing the carbides, to substantial machining of the bit body.

The bits were tested in two frozen soils, one containing scattered small stones up to 2.0 in. (51 mm) in size. The bits were also used to drill in a roadway surface of asphalt pavement.

Short-term penetration rates were determined for 1-ft (0.31-m) increments. A spindle speed was selected for each run from one of three values that ranged from 90 to 250 rpm. We controlled the thrust to achieve maximum penetration while attempting to maintain a constant rpm. Thrust was also regulated to avoid lifting the drill from its stabilizer jacks. With this drill configuration, thrust did not exceed 1200 lb (544 kg). Several additional observations were made on the influence of rotation speed on hole clearing.

EQUIPMENT

Bits

The bits were purchased from Pengo Corporation and are part of their TCH series. They appear to be variants of bits originally described in literature from the SABRE Bit Company. The 6.5-in.-diameter bit is shown in Figure 1. The 9.5-in. bit has a different configuration, with a step in the wings (Fig. 2). Both have a pilot that is helpful in providing

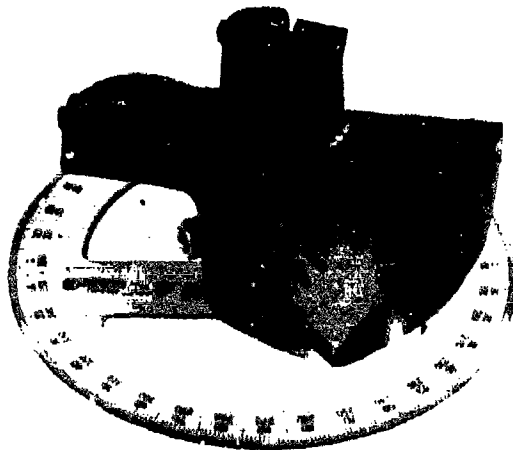


Figure 1. A Pengo Corporation TCH series 6.5-in.-diameter two-wing drag bit with pilot.

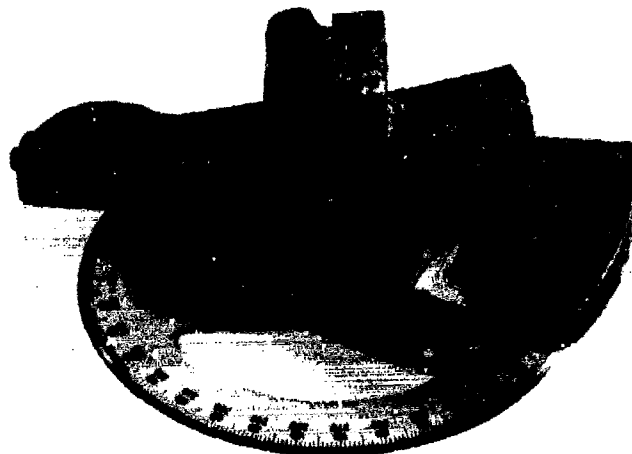


Figure 2. A Pengo Corporation TCH series 9.5-in.-diameter two-wing drag bit with step configuration and pilot.

stability during startup as well as during drilling. This series is marketed both as an independent bit and as a pilot for larger bits used in hard ground or frozen soil. The bits were also ordered with a drive lug having a 1-5/8 in. (41.3 mm) hexagonal shank.

These bits have carbide cutters that are set in approximately 45° milled slots. The carbides have a peaked configuration with an included angle of 80°, as shown in Figure 3. The measured relief angles of the carbides vary from less than 1° to 3°. (Figure 4 illustrates the bit angles used in this discussion.) The large, almost flat surface behind the cutters shown in Figure 3 tends to produce a 0° relief angle.

The carbides in the Pengo bits were replaced with Adamas carbides having material properties similar to those of the originals (Table 1). Two carbide shapes were selected for bit modification, both with included angles of 60° (Fig. 5). The peaked style on the left in Figure 5a is a direct replacement for the peaked, 80° included angle factory carbide. This replacement changed the relief angle to approximately 15° and the rake angle to approximately +15°, an increase of about 10° in both cases. The

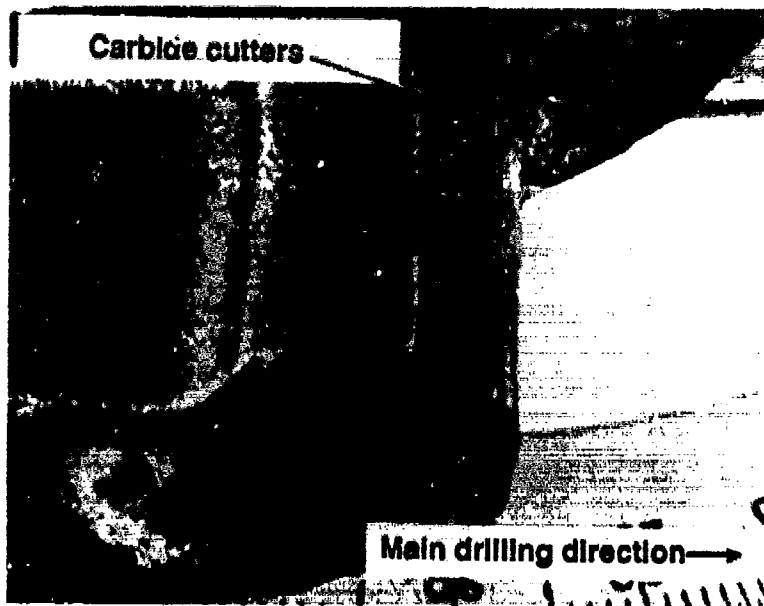


Figure 3. End of the cutter wing on the unmodified bit showing the carbide inserts. The carbides are symmetrical in cross section, with an 80° included angle.

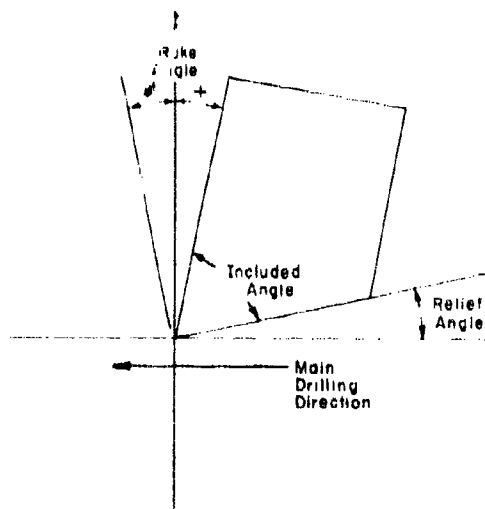
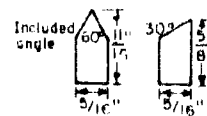
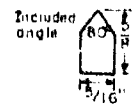


Figure 4. Carbide cutter showing the tool angles discussed in the text.



a. Adamas replacement carbides.



b. Original carbide.

Figure 5. Shapes of the carbides.



Figure 6. The 9.5-in. bit with minor modifications, including changing the carbides and some minor hand grinding to improve the relief angles.

bit shown in Figure 6 has this modification along with some minor hand grinding of the relief surface.

The other replacement carbide was used in a more extensive modification of the 9.5-in. step-wing bit (Fig. 7). This included milling new bit pockets on the wings and on the pilot. The pockets on the pilot were machined to a 0° rake, while the pockets on the wings were placed at two different angles. The angle on the inner step was 12° (positive), while the outer step had a positive angle of 16° . The flat section behind the cutters was removed, with the new surface corresponding to the cutter relief angle of the replacement carbide. The bit was also ground on the flow paths to assure unrestricted cutting flow. The drive shank was welded to the bit body so that the attachment bolt would not be required, since it projected into the cutting flow paths.

The bits were used with continuous-flight augers with diameters of $5\text{--}7/8$ in. (149 mm) and $8\text{--}7/8$ in. (225 mm) and flight pitches of 6 in. (152 mm) and 8 in. (203 mm), respectively. Auger sections 3 ft (0.914 m) and 5 ft (1.52 m) long were available for each of the bit sizes.



Figure 7. The 9.5-in. bit after modification, which included milling new carbide insert pockets and some grinding to streamline the cutting flow paths.

Table 1. Data on carbide inserts.

	Adamas	Standard Pengo
Series	502	MPD-2
Rockwell Hardness A	87.8	87.4
Density	14.37 gm/cm ³	14.39 gm/cm ³
Transverse Rupture Strength Minimal (ASTM)	390,000 psi	350,000 psi
Grain Size, Predominant	3-5 μ m	1-5 μ m
Cobalt	12%	11.5-12.25%
Tungsten Carbide	88%	88.5-87.75%

Drill

The drill used for the tests was a Mobile model B-34 mounted on a single-axle trailer (Fig. 8). It was selected only because it was available and had torque characteristics in the range commonly associated with small hydraulically driven drills. Features of the drill are shown in Table 2.

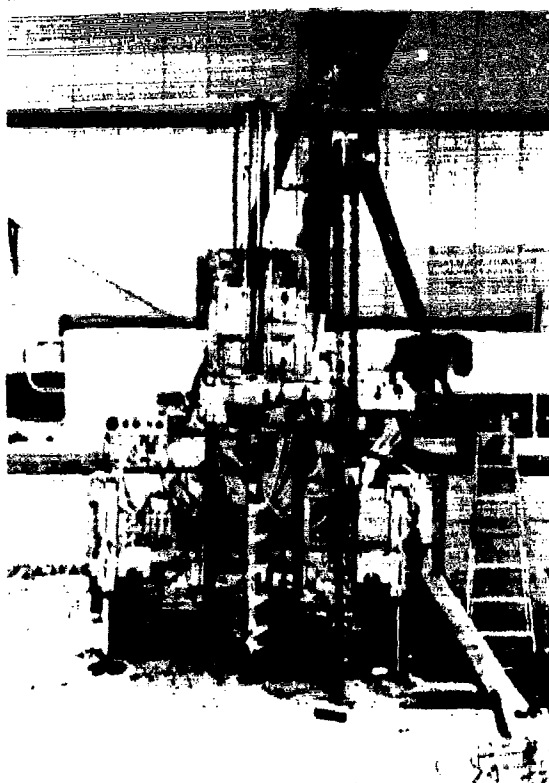


Figure 8. Mobile model B-34 drill atop the bin of frozen soil.

Table 2. Characteristics of the trailer-mounted Mobile model B-34.

Weight - 4650 lb (2109 kg)
 Stroke - 68 in. (172.7 cm)
 Spindle torque - 3275 lb-ft
 Speed range - 56-418 rpm
 Pulldown at 1500 psi (103.5 bar) - 7950 lb (3605 kg)
 Motor hydraulic system - 35 hp at 1580 rpm and 2000 psi (138 bar)
 Feed pump output - 25 gpm (1.58 L/s) at 2000 psi (138 bar)
 Rotation pump - 36 gpm (2.27 L/s) at 2000 psi (138 bar) and 2200 rpm

Transmission Gear	Ratio	Engine speed (rpm)	Spindle speed (rpm)
1	6.32 to 1	1400	50
		1800	70
2	3.09 to 1	1400	96
		1800	174
3	1.68 to 1	1400	195
		1800	253
4	1 to 1	1400	344
		1800	445

Test facilities and soil types

The bits were tested in two frozen soils with slightly different properties. The first series of tests was in a silty sand having an average dry density of 93 pcf (1.48 gm/cm^3) and containing scattered stone 1-2 in. (25.4-51 mm) in size. This section was slowly wetted from the surface prior to freezing, which caused a slight gradation in the moisture content with depth. The moisture content ($\text{wt}\cdot\text{H}_2\text{O}/\text{wt}\cdot\text{solids} \times 100$) in the upper 12 in. (305 mm) was approximately 27%; this was slightly higher than in the remaining frozen section. The moisture content was high enough to assure that the material was well bonded. Gravel particles were sufficiently held in the material to be cut on successive passes of the bit instead of being plucked from the fine-grained matrix. The frost depth was approximately 4.2 ft (1.3 m). The ground temperatures during drilling were around 20°F (-6.7°C). The soil was frozen in a large soil bin (22 x 24 x 8 ft, or 6.7 x 8.2 x 2.4 m) inside the CRREL Frost Effects Research Facility (FERF). After the freeze panels were removed, surface temperatures were controlled to prevent surface thaw. Grain size data are included in Figure 9, and they represent soil characteristics throughout the vertical profile.

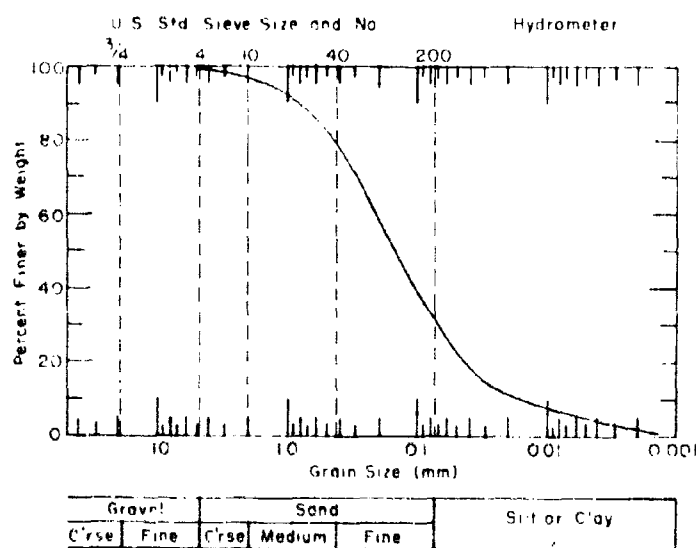


Figure 9. Grain size characteristics of the material in the test cell. This sample was from 2.25 to 2.75 ft (0.68 to 0.84 m) below the surface.

The second site was outdoors, in an area that was kept snow free, causing frost penetration of approximately 2.2 ft (0.66 m). The soil was a varved clay silt; no data are available for soil properties.

RESULTS

Soil tests

Both the modified and unmodified bits were tested. Penetration rates for the 6.5-in. and 9.5-in. bits were similar. Values for the modified bits in the natural soil ranged from 2.8 to 6.7 ft/min (0.8 to 2.0 m/min), with an average of 4.8 ft/min (1.5 m/min). The 9.5-in. unmodified bit, tested for comparison, was slower. Its rate was about four times less than the modified bit of the same diameter turned at the same rpm.

In the FERF, rates for the 9.5-in. bit ranged from 1.1 to 5.3 ft/min (0.3 to 1.6 m/min). The spindle rpm for these test runs ranged from 90 to 250. The average of the short-term runs with the 9.5-in. bit was 2.6 ft/min (0.8 m/min). The unmodified bit penetrated approximately 2 in. (51 mm) but then slowed to a stop, even with the drill picked up off one of the stabilizer jacks. Rates for the 6.5-in. bit varied from 3.0 to 4.6 ft/min (0.09 to 1.4 m/min) for an rpm range of 90 to 250. The average for five runs was 3.3 ft/min (1.0 m/min). The unmodified 6.5-in. bit drilled at less than half the rate of the modified bit turned at the same rpm (Fig. 10).

Drilling rates varied for a series of runs at the same rpm because of variations in material properties, primarily the amount of gravel encountered. The highest penetration rates were from runs at the two highest rpm settings (180 and 255). The range of values for runs at these two speeds was also similar, which may be due to the torque characteristics of the drill. The drill, when pushed to achieve maximum penetration at 255 rpm, may have lugged down to a value closer to the midrange.

Several additional observations were made regarding transport of cuttings from the hole. The auger was turned at one of five rpm settings in a cutting-filled hole with the bit held just off the bottom. We then removed the auger from the hole and estimated the amount of cuttings remaining on the flights (Figure 11). Our maximum speed of 340 rpm with the 9.5-in. bit produced the best clearing, with less than 10% of the flight area filled compared to about 35% after rotation at 170 rpm. The

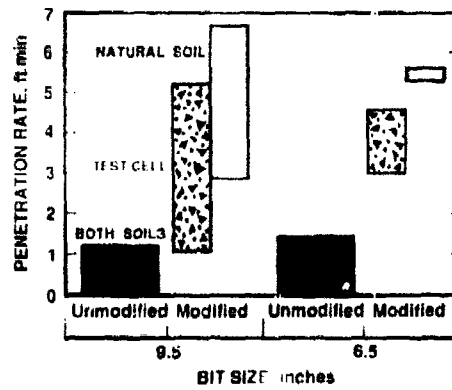


Figure 10. Performance of unmodified and modified bits in two frozen fine-grained soils.



Figure 11. Cuttings remaining on the flight of the 9.5-in. auger after a period of rotation at 90 rpm.

340-rpm speed for the 9.5-in. auger is close to the recommended speed for efficient operation of vertical screw conveyors (Colijn 1985). Unfortunately the speed required for best cutting transport is greater than can be used for drilling with auger drag bits of this size, in part because of the torque and rpm characteristics of drills and the limits placed by efficient drag bit cutting.

The bits used in the natural soil free of stone showed no sign of dulling after drilling about 10 ft (3.0 m). Most damage and wear to the bits used in the PERF were from impact with stones. However, after drilling 15 ft (4.6 m), the 9.5-in. bit was still in good condition and fit for drilling. Impact with stones slightly chipped several carbides. If these bits were used exclusively in frozen fine-grained soils, they could probably be used to drill more than 100 ft (30 m) of frozen material before the carbide would need to be sharpened. This is based on observations in frozen ice-rich silt near Fairbanks, Alaska, made by Delaney (in prep.), who reported that a drag bit with carbide cutters used with compressed air for cutting removal produced more than 650 ft of hole without noticeable dulling. Similar performance would be expected for our modified bits working in comparable materials.

Pavement test

A few tests were run on two road sections with asphalt pavement. The first had 3 in. (76.2 mm) of pavement, and the second had 8 in. (203 mm). These tests were done to determine the drilling characteristics of this material using these bits. The tests in the thin pavement were encouraging. The maximum short-term rates were 0.6 ft/min (0.2 m/min). However, the bits wore rapidly in the thick section, particularly in the lower part of the hole where the mix seemed dense and low in asphalt content. These pavements are part of a test section and are considered to have representative asphalt mixes, with stone in the 0.75-in. (19.0-mm) size. Dulling was rapid enough that it would have been difficult to drill more than three holes in the thick section before the bit would need sharpening.

CONCLUSIONS

Commercial auger bits well suited for drilling in frozen fine-grained soil are not available in the 3-10 in. (76.2-254 mm) size range. However, some models can easily be modified to perform efficiently. Tests with bits

modified for use in frozen soil on drills that have limited torque and thrust produced high penetration rates, ranging from 2 to 5 ft/min (0.6 to 1.5 m/min).

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