Special Report 88-8

July 1988

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

(2)

AD-A199 415

Evaluation of several auger bits in frozen fine-grained soils, asphalt, and concrete

Paul V. Sellmann and Bruce E. Brockett

DRILLING TECHNOLOGY NOTE

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp Date Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Special Report 88-8	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Cold Regions Research and Engineering Laboratory 6b. OFFICE SYMBOL (If applicable) CECRL	7a. NAME OF MONITORING ORGANIZATION Office of the Chief of Engineers
6c. ADDRESS (City, State, and ZIP Code) Hanover, New Hampshire 03755-1290	7b. ADDRESS (City, State, and ZIP Code) Washington, D.C. 20314-1000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO
6.27.30A	4A762730AT42	CS	035

11. TITLE (Include Security Classification)
Evaluation of Several Auger Bits in Frozen Fine-grained Soils, Asphalt, and Concrete
Drilling Technology Note

12. PERSONAL AUTHOR(S)
Sellmann, Paul V. and Brockett, Bruce E.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ______ TO ______	July 1988	14

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Auger bits, Drill bits, Drilling, Drill performance, Frozen ground. (SDW)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Several auger bits were evaluated for drilling in frozen ground, asphalt, and concrete to determine bit performance in a wide range of materials. Promising bits in the 9- to 10-in. (229- to 254-mm) diameter range were used with varying success depending on bit configuration. Bits included finger bits and a two-wing bit with continuous cutters. It was possible to penetrate all the test materials, with performance depending on bit parameters and characteristics of the drill rig. Drill rig specifications are important because of the high torque and vertical thrust required for drilling in these hard materials. The finger bits have an advantage over bits with fixed cutters (soldered to the bit) for this demanding drilling, since damaged and dull cutters can be rapidly replaced in the field without special equipment. Several smaller-diameter bits 3.5 in. (89 mm) to 6.5 in. (165 mm) were also tested in frozen ground only.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Paul V. Sellmann	22b. TELEPHONE (Include Area Code) 603-646-4100 22c. OFFICE SYMBOL CECRL-EC

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

PREFACE

This report was prepared by Paul V. Sellmann, Geologist, Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, and Bruce E. Brockett, Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. This work was done as part of Project 4A762730AT42, *Design, Construction, and Operations Technology for Cold Regions*; Task CS; Work Unit 035, *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 John Rand for reviewing this report. They also acknowledge the staff in the Frost Effects Research Facility for preparing an area for drilling in frozen soil, as well as the assistance provided in the Laboratory and the field by Chris Berini.

The contents of this report are not to be used for advertising or promotional purposes and are not intended to provide any positive or negative impact on commercial products. Citation of brand names does not constitute an official endorsement or approval of the use of commercial products. Brand names of the bits are not used; however, they can be obtained by contacting the authors.

CONTENTS

ILLUSTRATIONS

Figure

TABLE

Table

Evaluation of Several Auger Bits in Frozen Fine-Grained Soils, Asphalt, and Concrete

PAUL V. SELLMANN AND BRUCE E. BROCKETT

INTRODUCTION

The performance of several auger bits was evaluated to determine whether a general-purpose bit could be selected for use in a wide range of materials, including frozen ground. Part of this investigation was done in conjunction with the U.S. Army Armor and Engineer Board, Fort Knox, Kentucky. Auger drilling was part of their concept evaluation of a Canadian Specially Equipped Vehicle (an M113 modified for engineer support). The auger bit used during their evaluation was included in the CRREL tests. A drill rig with characteristics similar to the drill mounted on the M113 was used. The performance of both commercial and modified bits was compared for drilling in frozen ground, in asphalt, and in concrete pavements. Bit diameters were about the same: 9 to 10 in. (229 to 254 mm), which is the size needed for installation of cratering charges.

Several smaller-diameter auger bits were also tested in frozen ground to provide options for drilling with smaller and more portable drilling equipment. These bits ranged in size from 3.5 in. (89 mm) to 6.5 in. (165.4 mm); they included a commercially available finger bit and several wing bits fabricated at CRREL.

EQUIPMENT

Auger bits

Bit A is the bit used at Fort Knox with the drill mounted on the modified M113. It is a two-wing bit containing 12 carbide-tipped cutters. Pairs of cutters are held in place by a locking wedge (Fig. 1). The wedge and cutters are easily driven out with a hammer and punch, allowing for rapid cutter replacement. Incorporated on the bit body is a short section of flight to aid cutting transport.

Another style of finger bit (bit B) was obtained for additional performance information. It was selected from product literature, seeming to meet our design criteria for frozen ground drilling. A summary of these criteria follows:

1) The bit should cut the entire hole face, leaving no uncut ribs.
2) It should have unobstructed flow paths for cuttings.
3) It should have cutting angles and a bit body with proper geometry for efficient cutting.
4) The cutters should be durable and sharp.
5) The bit should have a balanced design, with stability, and be smooth running.

A detailed discussion of these criteria can be found in Sellmann and Mellor (1986) and Sellmann and Brockett (1986).

Bit B was selected in two diameters: 9 in. (229 mm) and 6 in. (152 mm). They are referred to as bits B-9 and B-6. These bits have three wings with carbide-tipped finger cutters (Fig. 2). The cutters are positioned to produce full face cutting in a step pattern. When properly seated, each cutter is fixed at a slightly different angle that is determined by the radial distance from the center. This assures ideal placement and orientation for the path being cut. The cutters have a tapered shank and are individually removed by driving a tapered punch through a hole in the bit body.

A third type of bit used during these tests were modified two-wing drag bits, one of 9.5 in. (241 mm) diameter (Fig. 3), and one of 6.5 in. (165 mm) diameter. Both of these bits were modified at CRREL for use in frozen fine-grained soil and will be referred to as bits C (Sellmann and Brockett 1986). These efficient frozen-ground bits provided a basis for evaluating finger-bit performance.

Drive unit

The drill rig used for the tests was a Mobile Model B-34 mounted on a single-axle trailer (Fig. 4). This drill rig has torque characteristics in the range commonly associated with small hydraulically driven drills. Mounted on the trailer, the drill's maximum thrust is limited to 1200 lb (544 kg) due to the light weight of the trailer and drill

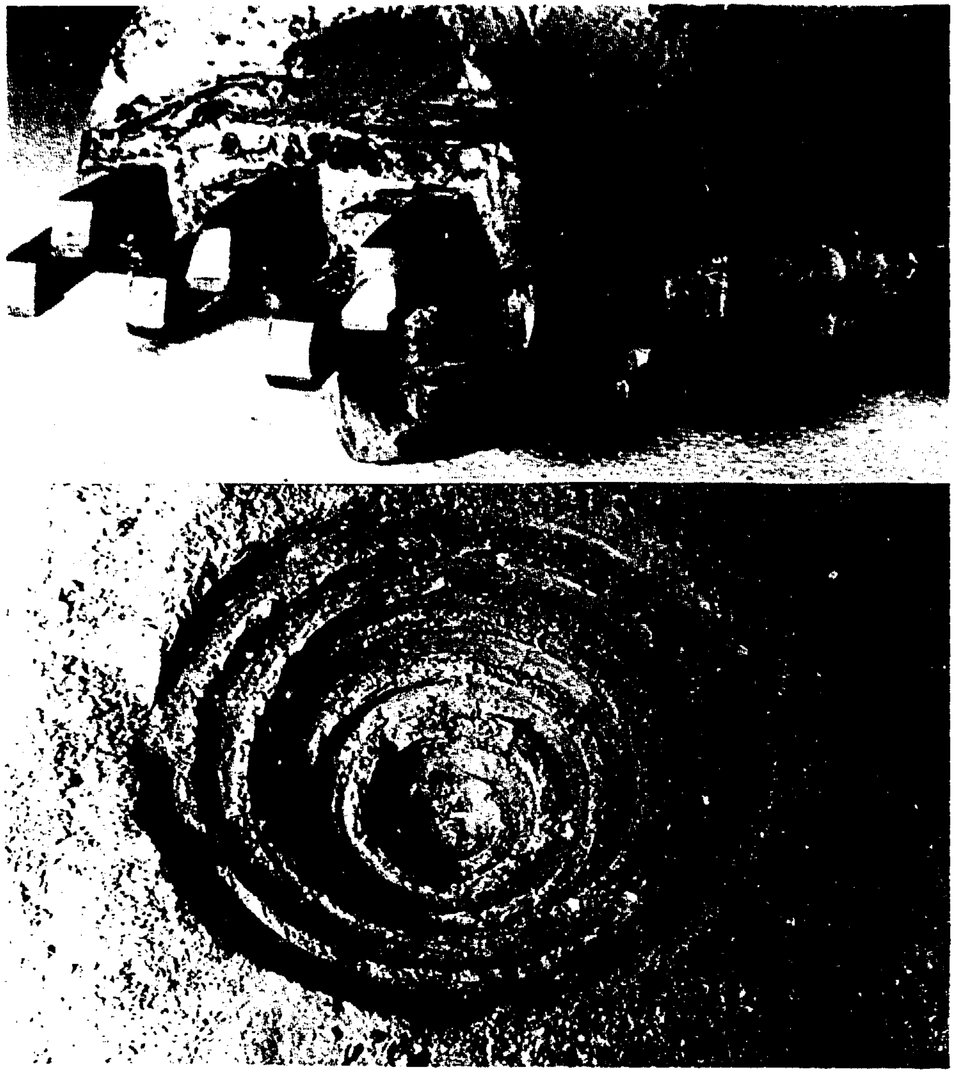

Figure 1. Bit A, a two-wing finger bit with tungsten-carbide-tipped cutters. The lower photo shows the cutting pattern in frozen ground; uncut ribs remain between the kerfs in the ductile material.

Figure 2. Bit B, a three-wing finger bit with tungsten-carbide-tipped cutters. This bit leaves no uncut material, as shown in the hole started in frozen ground.

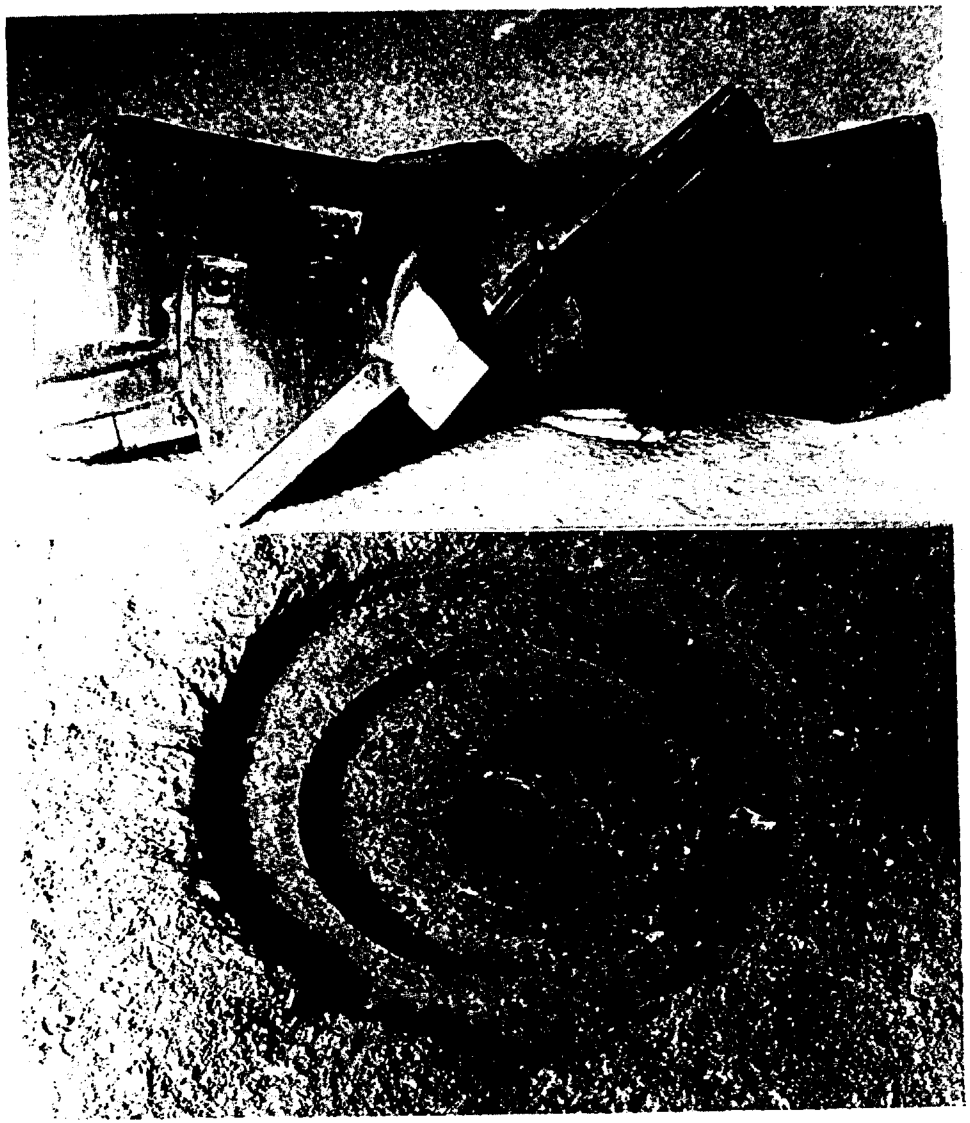

Figure 3. Bit C, a two-wing drag bit with continuous tungsten-carbide cutters. The bit has a pilot and cuts full face in a step pattern, as shown in the lower photo.

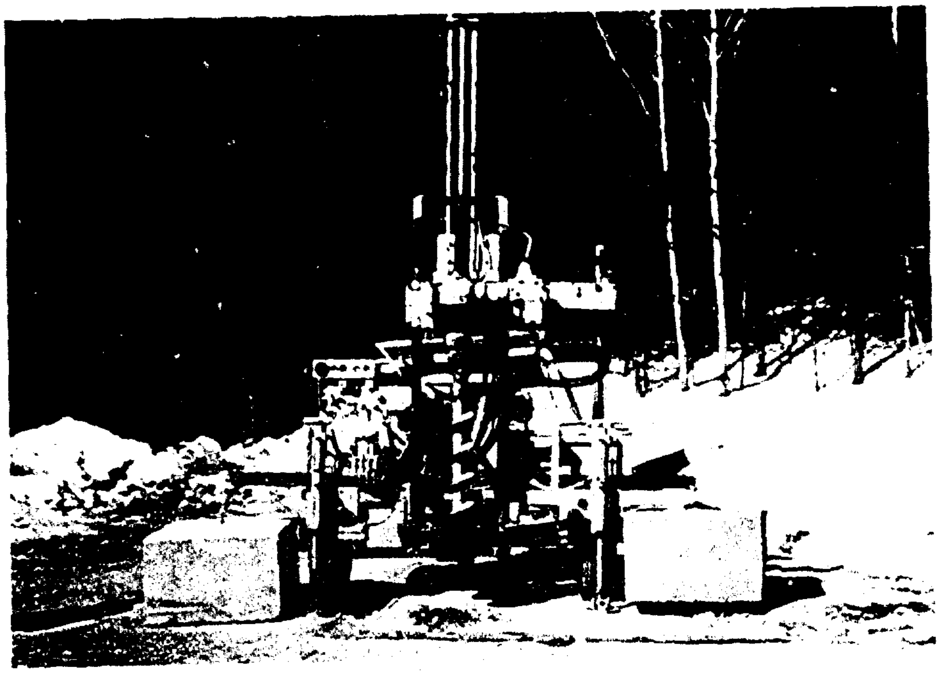

Figure 4. Mobile Model B-34 mounted on a single-axle trailer, with concrete reaction blocks in place.

rig combination. Features of the drill are shown in Table 1. For test purposes, two concrete reaction blocks (Fig. 4) were used to increase thrust to a level comparable to the drill mounted on the M113. Removable outriggers were added to the rear of the drill to attach these blocks. Each block is approximately 54 × 36 × 24 in. (1.37 × 0.91 × 0.61 m) high and weighs about 4000 lb (1816 kg). When the blocks were used to stabilize the drill it was possible to achieve more than a sixfold increase in thrust.

Table 1. Characteristics of the trailer-mounted Mobile Model B-34 drill rig.

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	1800	445

Weight—4650 lb (2109 kg) Spindle torque—3275 lb-ft
Stroke—68 in. (172 cm) Speed range—56-418 rpm
Pulldown at 1500 lb/in.² (10.3 MPa)—7950 lb (3605 kg)
Motor hydraulic system—35 hp at 1580 rpm and 2000 lb/in.² (138 bar)
Feed pump output—25 gal/min (1.58 L/s) at 2000 lb/in.² (13.8 MPa)
Rotation pump—36 gal/min (2.27 L/s) at 2000 4b/in.² (13.8 MPa) and 2200 rpm

FROZEN SOIL

The first series of tests was conducted in a frozen silty sand having an average dry density of 93 lb/ft³ (1.48 mg/cm³) and containing scattered stone 1 to 2 in. (25 to 50 mm) in size. The soil was frozen in a large soil bin (22 × 24 × 8 ft, or 6.7 × 8.2 × 2.4 m) inside CRREL's Frost Effects Research Facility (FERF). Slowly wetting the soil from the surface prior to freezing produced a slight decrease in the moisture content with depth. The moisture content (wt•water/wt•solids) in the upper 12 in. (305 mm) was approximately 27%, 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 held sufficiently to be cut on successive passes of the cutters without being plucked out. After the freeze panels were removed, soil surface temperature and air temperature were controlled to slow the surface thaw. The frost depth was approximately 4.2 ft (1.3 m) and the ground temperature was around 20°F (-6.7°C). Representative grain-size data throughout the vertical soil profile are included in Figure 5.

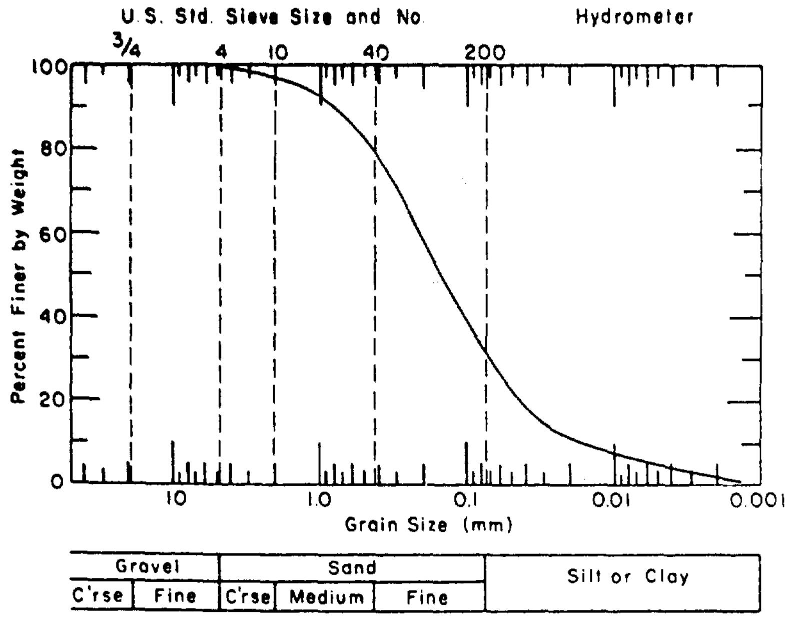

Figure 5. Representative grain-size distribution of frozen soils in the FERF test cell.

CONCRETE

Testing was done at two different locations. Location 1 consisted of two pads poured at the southwest end of CRREL's highway test section. Each pad was 9 ft × 9 ft × 6 in. (2.7 × 2.7 × 0.15 m) thick. The southernmost had two layers of 1/8-in. thick (3.2-mm) steel reinforcing mesh; for contrast the adjacent pad was poured without the reinforcing mesh. Concrete in these pads tested at an average of 3000 lb/in.^{2} (20.7 MPa). The pads were underlain by a sandy gravel over the local clayey silt. Concrete at the second location, a storage pad, had an unconfined compressive strength of 8800 lb/in.^{2} (60.7 MPa). The reinforcing mesh at the second site was 3/16 in. (4.8 mm) in diameter. In this report the concrete at location 1 is referred to as weak and at location 2 as stronger.

ASPHALT

Asphalt drilling was done in two roadway surfaces of different thicknesses, one 3 in. (76.2 mm) and the other 9 in. (228.6 mm) thick. These pavements were part of a highway test section, and they are considered to have representative asphalt mixes, with stone about 0.75 in. (19.0 mm) in size. A hole drilled into this material with bit C (Fig. 6) shows the cut stone in the partially penetrated pavement. The 9-in. (228.6-mm) section seemed hard, very dense, and low in asphalt content. The two pavement surfaces are described in this report as hard and soft asphalt.

TEST PARAMETERS

The penetration rate of each bit was determined during a series of short-term penetration runs

Figure 6. Typical asphalt materials, showing stone size.

while attempting to maintain maximum thrust. The rotational speed was set prior to penetration and was not adjusted during individual runs. The rpm was selected to provide maximum performance with maximum application of thrust. Drilling in harder material, such as the concrete and asphalt, required lower gearing for greater torque; first gear was used for all these runs, with the spindle speed set at 55 rpm. Frozen-ground drilling with these bits required much less torque, so for maximum performance all the tests were run at higher gearing (third gear), at around 250 rpm. The reduction in rotational speed during each run was also recorded, since this helps illustrate the cutting and transport efficiencies of each bit.

RESULTS

The penetration rates and rotational speed (rpm) data are plotted in Figures 7 and 8. More details concerning other aspects of the bits are cov-

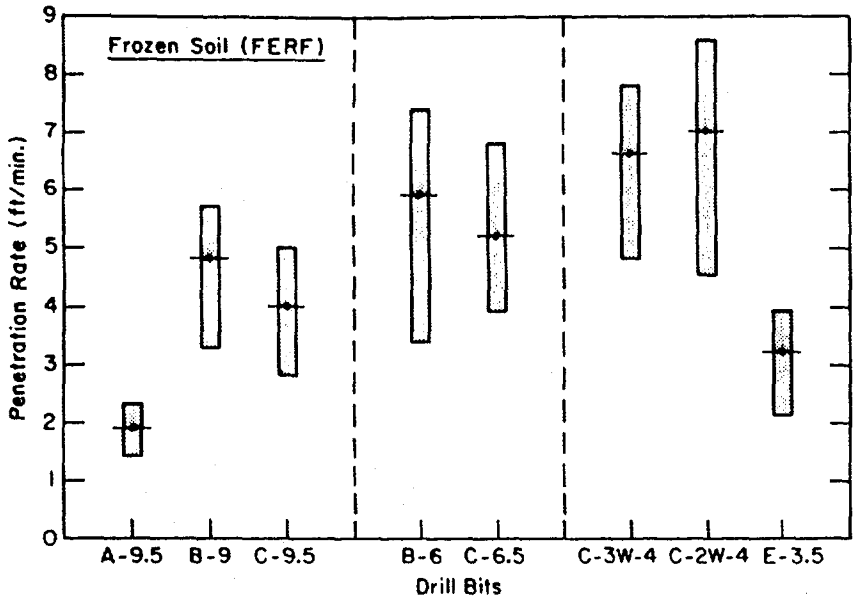

Figure 7. Penetration rates in frozen fine-grained soil.

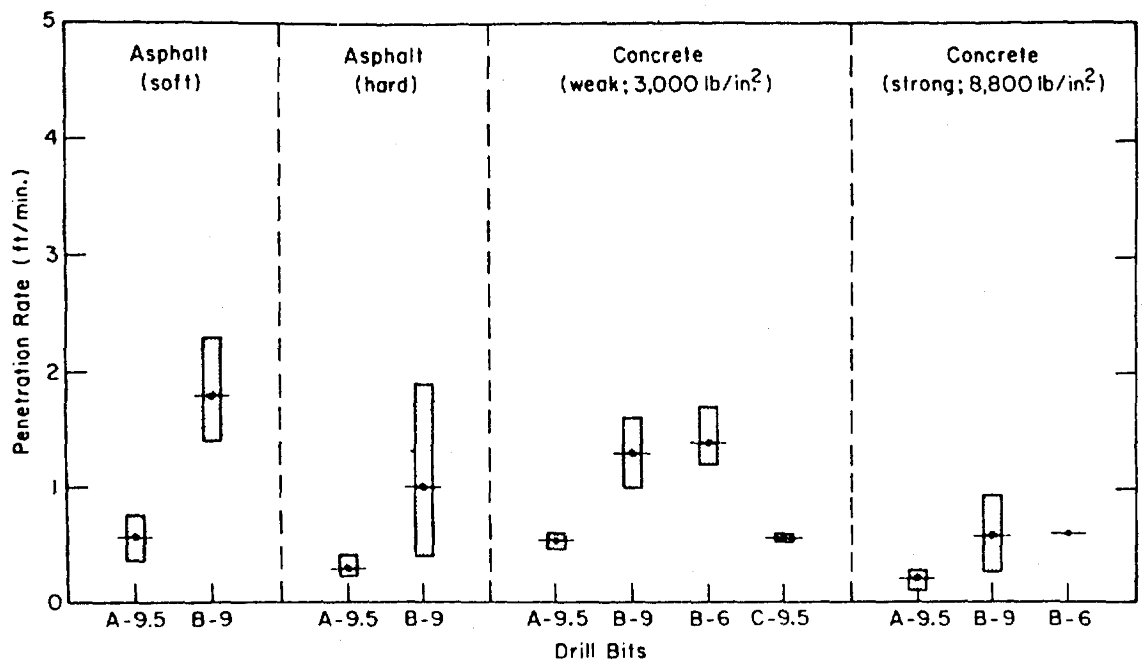

Figure 8. Penetration rates in asphalt and concrete.

ered in the separate discussions of the specific bit size and style. No reaction blocks were used during the frozen-ground and asphalt test runs. All the data used in the summary shown in Figures 7 and 8 are for the current tests, except for some data from previous frozen-ground drilling with the 9.5-in.-diameter bit C. In this case the only data used were for runs at the gearing and rotational speed used during this test series.

Bit A-9.5

The cutters of this finger bit are placed on two wings, they are staggered, and pairs are wedged in place. Each pair of cutters tends to track in the groove cut by the corresponding cutters on the opposite wing. During our tests, this configuration formed uncut ribs, such as those shown in Figure 1. The ribs and the angle of the cutters in relation to the cutting paths caused noticeable wear, particularly when working in hard, abrasive materials (Fig. 9). The wear occurs on the sides of the cutters and on trailing surfaces behind the carbides of cutters near the bit center.

When drilling in frozen soil, an average penetration rate of 1.9 ft/min (0.6 m/min) was achieved. In soft asphalt the average penetration rate was 0.57 ft/min (0.17 m/min), and in hard asphalt it was 0.3 ft/min (0.01 m/min). The average rate in the weak concrete was 0.54 ft/min, and it was 0.2 ft/min in the stronger concrete (0.17 m/min and 0.06 m/min respectively). Reaction blocks were used during the concrete tests.

Penetration rates in the frozen ground were slowed by plugging of the bit. Cuttings jammed under the short section of flight on the bit body, requiring that cuttings be squeezed up around the edge of this flight. This bit also had a tendency to be less smooth-running than the others.

Bit B-6

The B bits are three-wing finger bits with cutters spaced to provide full face cutting. The first run with this bit in frozen ground was unexpectedly slow (approx. 2 ft/min, or 0.6 m/min). Upon examining the orientation of the bit in relation to the auger flights, we found that the bit was misaligned. The auger flight created a restriction in one of the cutting flow paths, plugging the bit. Rotating the bit 180° on the auger solved the problem. On all subsequent runs the cuttings flowed freely onto the flights. The restriction of cutting flow and associated plugging of the bit caused more than a 65% reduction in the penetration rate.

This bit penetrated at an average rate of 5.9 ft/min (1.8 m/min) in the frozen soil, cutting aggressively, shaving and chipping the stones, and it had little tendency to wander in the hole. With this bit design the entire hole bottom is cut, and wear on the sides of the cutters is minimal. This bit was tested at both concrete sites without reaction blocks. In the weak concrete the average penetration rate was 1.4 ft/min (0.4 m/min), compared with 0.6 ft/min (0.18 m/min) in the strongest concrete (Fig. 8). Thrust without the reaction blocks was just over 1000 lb (454 kg).

Bit B-9

Bit B-9 (shown in Fig. 2) is similar to bit B-6.

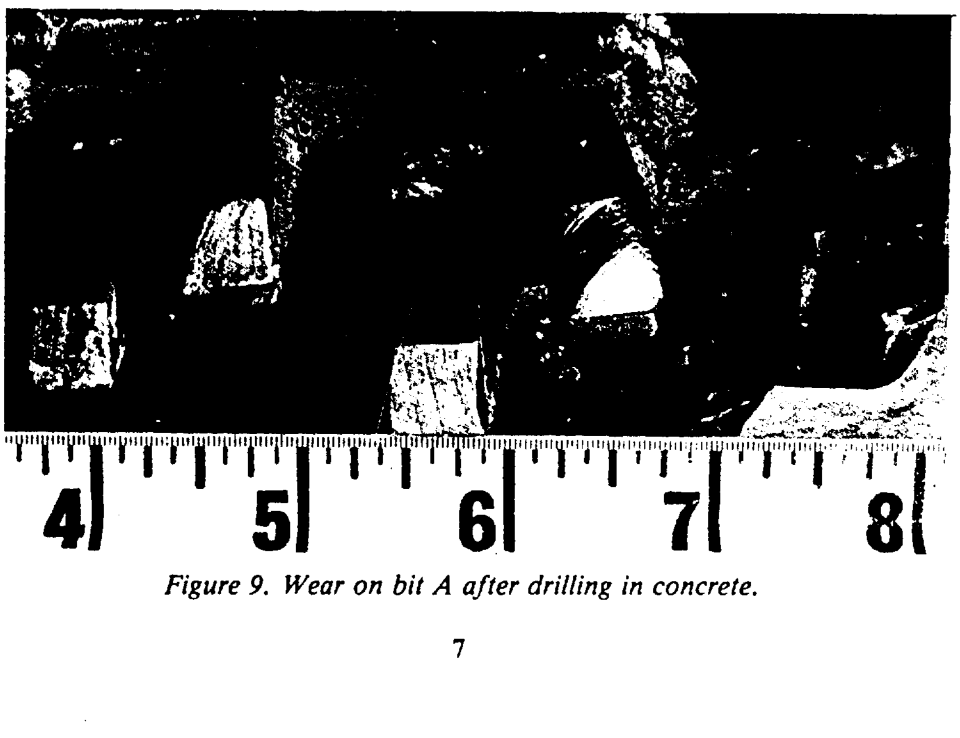

Figure 9. Wear on bit A after drilling in concrete.

The average penetration rate in frozen ground was 4.8 ft/min (1.5 m/min) (Fig. 7). This is an aggressive but smooth-running bit that easily handled all the stone encountered during these tests.

The bit was tested in asphalt without reaction blocks. In the soft asphalt the average penetration rate was 1.8 ft/min (0.55 m/min), compared with 1.0 ft/min (0.3 m/min) in the hard pavement. Penetration rates in the concrete tests with the reaction blocks averaged 1.3 ft/min (0.4 m/min) in the weak concrete and 0.6 ft/min (0.18 m/min) in the stronger concrete. The range in the penetration rates (Fig. 8) reflects the effects of bit wear.

Bit C-9.5

Bit C-9.5 is a two-wing drag bit with continuous blade cutters. It also has a pilot and cuts a three-step pattern (Fig. 3). This 9.5-in.- (241-mm-) diameter bit produced holes in the frozen ground at an average rate of 4.0 ft/min (1.2 m/min) with the least reduction in rpm (Fig. 7 and 12) under load. In the weak concrete a penetration rate of 0.56 ft/min (0.17 m/min) was attained. This blade bit works well in frozen ground. The larger linear dimension of the cutters limits the thrust that can be applied to individual cutters compared to the finger bits, making the finger bits better suited for pavement drilling where high vertical cutter loading is required.

The 6.5-in. (165-mm) version of this bit produced holes in the frozen ground at an average rate of 5.2 ft/min (1.6 m/min).

Figure 10. Two-wing and three-wing auger bits (4-in. [101.6-mm] diameter) made from blades of commercially available bits that are commonly used for rotary drilling in frozen ground, often with compressed air for circulation.

Figure 11. Small-diameter finger bit E (3.5 in. [89-mm] diameter) tested in frozen ground.

Additional tests

Several smaller-diameter auger bits were also tested in the frozen ground. Two of these were made at CRREL, since we needed more candidates for use on lighter weight drilling units. Two 4-in.- (102-mm-) diameter wing bits were made from drag bits that have been used successfully in frozen soils on systems that require circulation (Fig. 10). A three-wing variation was constructed in hopes of improving the drilling capability of small drills in frozen soils that contain some rock. Both the two- and three-wing bits performed well; rates for the three-wing bit averaged 6.6 ft/min (2.0 m/min), compared with 7.0 ft/min (2.2 m/min) with the two-wing bit (Fig. 7, 3W-4 and 2W-4). These rates were compared to the performance of a 3.5-in. (89-mm) commercial two-wing finger bit, bit E-3.5 (Fig. 11), which drilled at a rate of 3.3 ft/min (1.0 m/min) (Fig. 7).

DISCUSSION

All of the bits penetrated the test materials, but with considerable variation in performance. The best overall performance was given by the B-style finger bits. No problems were encountered with bit clogging and unusual bit wear. The C bits also performed well in the frozen fine-grained soil for which they were designed. They ran smoothly, with the pilot bit making it easy to start. Lack of rapidly replaceable cutters makes the C bits less suited for drilling in asphalt and concrete, where rapid dulling of the cutters can be expected.

During the asphalt and concrete drilling summarized in Figure 8, the importance of sharp cutters was apparent. Each series of runs, in a new material or at a new site, started with sharp cutters. In all cases penetration rates decreased noticeably during a series of test runs, with the influence of dulling most noticeable in the hard asphalt and stronger concrete. The highest rates shown in Figure 8 were usually for the first run. For example, in weak concrete bit B-9 dropped from 1.6 to 1.0 ft/min (0.5 to 0.3 m/min) after five 6-in. (152-mm) runs. In strong concrete, the penetration rates went from 0.95 to 0.25 ft/min (0.30 to 0.08 m/min) after only three 6-in. (152-mm) runs.

The monitoring of drop in rotational speed (rpm) during drilling makes it possible to comment qualitatively regarding bit performance and efficiency for the frozen ground drilling. Figure 12 shows percent rpm reduction from unloaded rpm for the bits. The greatest reductions were for bit B-9 and bit A, which had the highest and lowest penetration rates respectively. Bit C-9.5 had the least drop and had penetration rates that were near those for bit B. Bit B was very aggressive and it fed rapidly without showing signs of lifting the drill rig. The depth of cut per revolution probably accounted for the rpm drop. The lower drop for bit C-9.5 seems related to its less aggressive cutting action. With less than 1000 lb (454 kg) of thrust and with the higher rpm, the depth of cut per revolution is less than with bit B. In contrast, bit A with low penetration rates and a large drop in rotational speed (rpm) apparently reflected the disadvantage of operating with the bit partially plugged due to obstructed cutting flow. This plugging caused considerably more friction in the hole, since cuttings had to be forced up between the small section of flight on the bit and the hole wall.

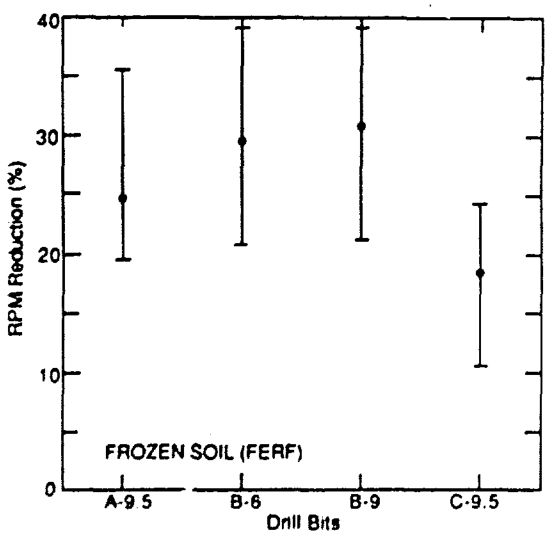

Figure 12. Percent rpm reduction for each bit during the drilling runs.

The B finger bits showed no unusual cutter wear. All wear was concentrated on the carbide inserts and on the center cutter, which on two occasions rotated in the pocket, causing wear on the side of the cutter. In hard drilling (e.g. pavements), cutter placement and orientation in bit A caused wear on the sides of some cutters due to the uncut ribs. Wear also occurred on the upper bit surfaces (Fig. 9) of the center cutters, since they were not oriented well in relation to their cutting paths. Contact of material with noncutting bit surfaces also compromises bit performance, since the energy available for drilling is reduced and the wear surfaces increase the thrust requirements.

CONCLUSIONS

Of the bits evaluated during our tests. the three-wing finger bits (B-6 and B-9) provided the best performance, and they appear to be the best of this group for general-purpose drilling in a wide range of materials. Drilling through concrete and asphalt pavement with the finger bits is possible if sufficient thrust and torque can be provided and if the cutters are replaced when they become dull.

Auger drilling in concrete requires that the drill unit be mounted on a carrier that has sufficient weight and stiffness for reaction and stability. Both the drill mounted on the M113 and our B-34 with reaction blocks appeared to provide adequate reaction. The finger bits are also most practical, since badly worn or broken cutters can be replaced rapidly without complicated tools or without returning the bit to a shop for rebuilding.

Performance in some types of frozen ground will not be as good as the test performance in the frozen fine-grained soil in the test cell. Difficult drilling and much lower rates can be expected for frozen gravel and for soil with large stones.

REFERENCES

Mellor, M. and P.V. Sellmann (1975) General considerations for drill system design. USA Cold Regions Research and Engineering Laboratory, Technical Report 264.

Sellmann, P.V. and B. Brockett (1986) Auger bit for frozen fine-grained soil. USA Cold Regions Research and Engineering Laboratory, Special Report 86-36.

Sellmann, P.V. and M. Mellor (1986) Drill bits for frozen fine-grained soil. USA Cold Regions Research and Engineering Laboratory, Special Report 86-27.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1988--500-050--82002