SR 146

Special Report 146

USA CRREL SNOW AND ICE TESTING EQUIPMENT

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September 1975

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Special Report 146	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* USA CRREL SNOW AND ICE TESTING EQUIPMENT		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Herbert Ueda, Paul Sellmann and Gunars Abele		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		12. REPORT DATE September 1975
		13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Cutting tools	Snow
Ice	Thickness
Ice reporting	

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This paper summarizes available information on the history, development, and application of three items of special equipment designed or modified by USA CRREL for testing and sampling snow and ice. These items have become universally known and accepted, providing measurement techniques that are used, in some cases, on an international basis. The equipment described includes the 3-in. ice coring auger, the ice thickness kit, and the Rammsonde.

PREFACE

This report was prepared by Herbert Ueda, Research Mechanical Engineer; Paul Sellmann, Geologist; and Gunars Abele, Research Civil Engineer. Mr. Ueda is a member of the Technical Services Division. Mr. Sellmann and Mr. Abele are members of the Northern Engineering Research Branch and the Applied Research Branch, respectively, of the Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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USA CRREL SNOW AND ICE TESTING EQUIPMENT

by

Herbert Ueda, Paul Sellmann and Gunars Abele

INTRODUCTION

This paper summarizes available information on the history, development, and application of three items of special equipment designed or modified by the U.S. Army Cold Regions Research and Engineering Laboratory for testing and sampling snow, ice and frozen fine-grained soils. These items have become universally known and accepted, providing techniques that are used, in some cases, on an international basis. The equipment described includes the 3-in. (7.6-cm) ice coring auger, the ice thickness kit, and the Rammsonde. A fourth item not covered here, the snow density kit, is described in CRREL Instruction Manual 1, *Instructions for Making and Recording Snow Observations*. This kit contains necessary equipment for determining snow density, temperature and an index of strength.

CRREL 3-INCH ICE CORING AUGER

The CRREL ice auger has been used throughout the cold regions of the world for drilling and sampling in snow, ice and frozen organic and fine-grained mineral soils. It has proved to be a valuable tool since it provides a rapid, portable and inexpensive means of taking large, undisturbed samples from many materials found near the earth's surface in the cold regions. It takes a 3-in. (7.6-cm) core and produces approximately a $4^3/_8$-in. (11.1-cm) diameter hole, and under most conditions it can be used by hand without a power drive. If a power drive is desired, a variety of electric or gasoline hand-held powered sources can be adapted to the unit.

The original ice coring auger was developed at the Arctic Construction and Frost Effects Laboratory (ACFEL)* in the late 1940's, and a completed design was produced in 1950 as part of an ice mechanics test kit for the U.S. Navy Hydrographic Office (Fig. 1); another version of the unit was designed as part of a small, powered drilling rig (ACFEL 1954, SFFEL 1950, Linell 1954).

This basic auger was modified by the Snow, Ice and Permafrost Research Establishment (SIPRE)* in 1955-56 to its present configuration, prompted by the need for a snow and ice investigation kit by the U.S. Navy and field parties for the approaching IGY. Changes in the coring auger included: 1) lengthening the barrel and flights, 2) changing the top flange above the flights to provide passage for the cuttings, 3) adding holes in the barrel wall, and 4) adopting a system of core removal through the top of the barrel.

* In 1961 ACFEL and SIPRE were merged to form CRREL.

Figure 1. Original ice coring auger made by ACFEL illustrating how cores were removed by sliding them into the core remover.

The complete auger kit now consists of a core barrel assembly with cutting shoe and cutters, a driving head, a turning brace, a T-handle, five extension rods which provide a 20-ft (6.1-m) depth capability, a starting guide, and an extra set of cutters. The components are contained in a 45 × 15 × 5-in. (114 × 38 × 13-cm) plastic-covered wood carrying case (Appendix A). Total kit weight is about 100 lb. Early kits were manufactured by the General Mechanical Company, Chicago, Illinois, and at the present a commercial source for the equipment still exists.

At CRREL a few additional changes have been made on a few auger kits to improve their performance and durability with power drives when used in frozen fine-grained organic and mineral soils (Cole and Sellmann 1968). These modifications included: 1) a heavy-duty drive head, 2) tungsten carbide cutters, 3) adapters for a variety of power drives, and 4) elimination of holes in the core barrel wall (Fig. 2). In addition a number of core barrels patterned after the original design have been constructed to obtain cores ranging in diameter from 1 to 6 in. (2.5 to 15 cm), although none of these are part of the standard kit.

When this auger is being used for sampling, core length is limited by storage capacity for cuttings which collect in the barrel above the core. Near the surface where most of the cuttings are pushed out of the hole, a full-length core, approximately 3 ft (91 cm) long, can be obtained. In deeper drilling in ice, a maximum core of about 24 in. (61 cm) can be obtained before the barrel must be withdrawn and emptied. Allowing cuttings to collect above the barrel is not advisable since they can bridge across the hole, causing difficulties in auger retraction.

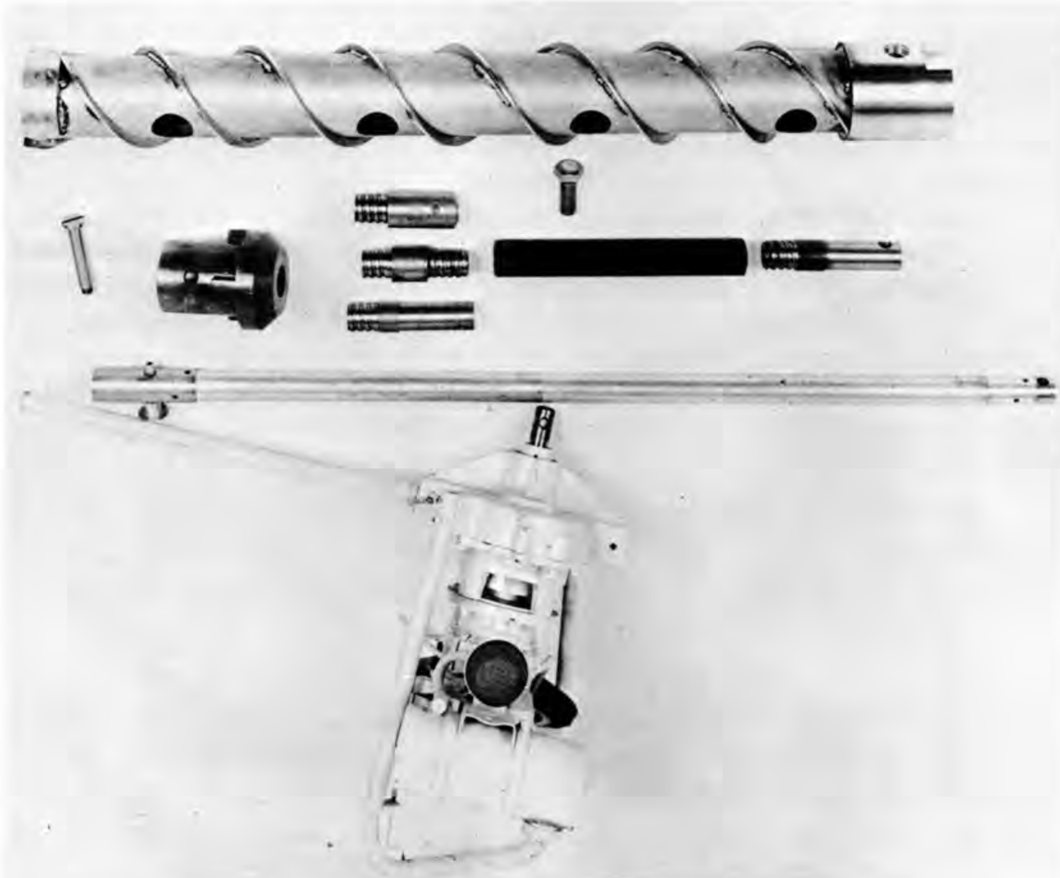

Figure 2. USA CRREL ice-corer with modified head and various adapters and small gas powered drive unit.

A core catcher is not provided since cuttings normally jam into the gap between the core and the cutting shoe or barrel and sufficiently retain the core during extraction from the hole. At the end of a drilling cycle, cores can usually be broken off by slightly jarring the auger or the string of extensions above the auger. Starting the auger, particularly on vertical surfaces, is made less difficult by a starting guide. The guide consists of a standard twist drill in a block of wood that is inserted into the bottom of the auger and then removed after the hole has been started.

Drilling rates in ice vary with ice type and temperature. A rate of 1.5 ft/min (46 cm/min) is possible by hand-turning at about 100 rpm in clean glacier or lake ice at -30°C, using sharp cutters and the auger's weight alone. In warm ice and in high density snow or firn, higher rates are possible.

Drilling rates in sea ice, when a hand brace was being used, ranged from 0.8 to 1.2 ft/min (24 to 37 cm/min); when the same tool was turned with a T-handle, the rates dropped to 0.43 to 0.61 ft/min (13 to 19 cm/min) (Kovacs 1970). With a gasoline drive, rates of 3.0 to 3.5 ft/min (91 to 107 cm/min) have been measured (Kovacs 1970). With a $^3/_4$-in. electric drill drive, penetration rates of 2.4 to 4.0 ft/min (73 to 122 cm/min) (Kovacs 1970) and 5.4 to 5.6 ft/min (165 to 171 cm/min) have been measured (Kovacs et al. 1973). The maximum practical depth for one man to core is about 20 ft (6 m). For greater depths, two men are advisable, as is the use of a wood chuck or a tripod to assist in holding the string of extensions when making and breaking the pinned couplings. The maximum recorded hand-drilled depth of 180 ft (55 m) was obtained in Greenland in glacier ice (Ragle et al. 1964).

Drilling rates in permafrost vary greatly depending on the type of drive system and the material being cored. The corer is best suited for frozen fine-grained material. In perennially frozen Fairbanks silt, as many as 30 1-ft (30-cm) cores have been obtained in four hours using a Skil 737 Roto Drive rotary percussion drill. In the bogs of central Alaska continuous cores were obtained from as many as six holes averaging 10 ft (3 m) in depth in six hours using a Mobil Drill B-26 as the power source. The auger was also used for sampling in permanently frozen bogs (moss peat, sedge peat and woody peat) to depths of 94 in. (2.4 m) by hand (Hughes and Terasmae 1963). A power-drive version of the early model auger obtained 18-in. (46-cm) cores in woody peat in 20-30 seconds using a McCulloch chainsaw motor drive, Model 35 C/W, or a Haynes Earth Drill, Model 400. Short term penetration rates of approximately 12 ft/min (3.7 m/min) have been obtained in ice-rich silt (Mellor et al. 1973).

Additional information including operating instructions for this coring auger can be found in Appendix A.

ICE THICKNESS KIT

This unit was developed for rapid manual drilling of small diameter holes to measure ice thickness. Its applications range from drilling holes in glacier ice for placing ablation and movement stakes to measuring thickness of lake, river and sea ice.

The first of these augers was designed by the Frost Effects Laboratory. The details of this design are covered in ACFEL Technical Report 25 (1950). The basic unit is a modification of a ship auger, and the presently available auger in the Ice Thickness Kit is a modified version of the early design. Recent tests of the 1.5-in. (3.8-cm) diameter auger driven with a hand-held $^3/_4$-in. electric drill provided rates ranging from 1.7 to 7.4 ft/min (0.5 to 2.3 m/min) depending on thrust (Kovacs et al. 1973). A list of items contained in the original kit, comments on its performance, and operating instructions which are provided with it are given in Appendix B.

Difficulties stemming from the poor chip clearing capability of these augers and increased cost of the ship auger type flights prompted the design and construction of a replacement for this auger. Recent cutter design research at CRREL provided the necessary background for the development of this and other new augers for frozen soil and ice (Kovacs et al. 1973, Kovacs 1974, Sellmann and Mellor 1974, Mellor and Sellmann 1974). The new auger has simple stainless steel flights with an ice bit similar to that developed by Kovacs (1974) for a larger series of augers. The bit can also be removed and replaced with a carbide bit for use in frozen soil. Another feature of the new auger is that flighted extensions can be used with the main flight as well as the conventional extensions. These new flighted extensions permit more continuous drilling in situations where deep holes are required.

This new version of the auger for the ice thickness kit is 1 m long and makes a hole approximately $1^7/_8$ in. (4.8 cm) in diameter. Penetration rates when the auger was turned with a hand brace ranged from 3 to 4 ft/min (0.9 to 1.2 m/min); the rate increased to more than 9 ft/min (2.7 m/min) when the auger was driven by an electric hand-held drill using very limited thrust.

In addition to this auger, a large number of augers of varying diameters have been constructed for a range of applications. None of these at present are part of a standard line such as the ice thickness kit (Appendix B). With a larger auger, 3 in. (7.6 cm) diameter, fitted with a high penetration rate ice bit and powered by a hand-held electric drill, rates as high as 10.4 ft/min (3.2 m/min) have been obtained (Kovacs 1974). A small auger 1.5 in. (3.8 cm) in diameter was also developed, primarily for use in frozen soil. When this auger was used with a hand brace, drilling rates up to 2.4 ft/min (0.7 m/min) were obtained in frozen silt (Sellmann and Mellor 1974). With electric drill drive units, the same hand augers penetrated frozen silt at rates up to 7.5 ft/min (2.3 m/min). Additional information on performance characteristics of augers and drills in general, developed by CRREL as well as by other organizations, is summarized and discussed by Mellor and Sellmann (1974).

RAMMSONDE

The Rammsonde ("Ram") was adapted by the U.S. Army and others from an instrument originally used in the Swiss Alps. It is used for determining a measure of the resistance to penetration of snow vs depth based on penetration of a cone under impact of known energy. It has found extensive application for estimating avalanche danger and for determining allowable wheel loads on artificially compacted snow pavements.

The Rammsonde is a cone penetrometer consisting of a hollow, 2-cm-diameter aluminum shaft with a 60° conical tip, a guide rod, and a drop hammer. The standard cone has a diameter of 4 cm and a height of 3.5 cm; the total length of the penetrometer cone element (to the beginning of the shaft) is 10 cm (Fig. 3). In fresh, low density (< 0.2 g/cm^3) snow, usually too soft for the standard cone, a modified 10-cm-diameter, 120° cone (not in the standard kit) has been used and found suitable (Abele 1968). The guide rod, inserted into the top of the shaft, guides the drop hammer.

The hammer is raised by hand to a certain height which is read in centimeters on the guide rod, and then dropped freely (Fig. 4). The depth of penetration is read from the centimeter scale on the shaft. The resistance to penetration (commonly referred to as hardness) of snow can be determined by observing either the amount of penetration after each hammer drop or the number of hammer drops (blows) necessary to obtain a certain penetration. In relatively hard, homogeneous snow it is usually more convenient to determine the number of blows needed to penetrate through some predetermined depth increment. Recording the number of hammer blows after each 5-cm depth increment is a convenient procedure commonly used. In layered and new, soft snows the more satisfactory procedure is to observe the amount of penetration after each hammer blow.

The standard Rammsonde kit contains two drop hammers, 1 kg and 3 kg in weight. A combination of one of the hammer weights and some drop height (range 0 to 50 cm) usually allows a suitable rate of penetration (between 1 cm per 5 hammer blows and 5 cm per blow) in a great variety of snows. Of course, the fewer hammer weight and drop height combinations used during a series of tests, the more convenient is the subsequent data reduction.

The ram resistance is computed from the following expression:

$$R = \frac{Whn}{x} + W + Q$$

where R = Ram resistance (kgf)

W = weight of drop hammer (kgf)

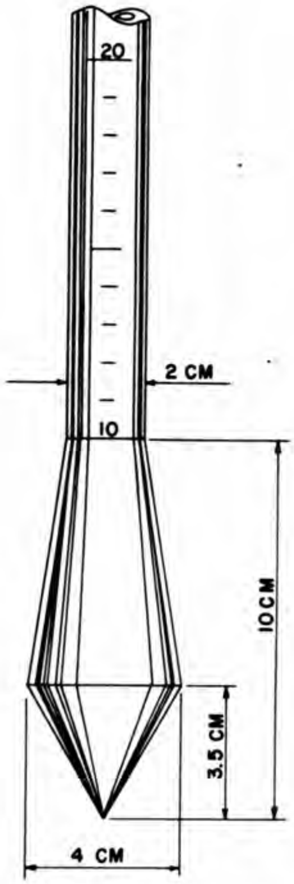

Figure 3. Rammsonde penetrometer cone.

Figure 4. Rammsonde penetrometer in use.

h = height of drop (cm)

n = number of hammer blows

x = penetration after n blows (cm)

Q = weight of penetrometer (kgf).

The ram resistance number R is an arbitrary index which indicates the resistance in kilograms offered by snow to the vertical penetration caused by ramming a metal cone of given dimensions. The resistance reading at any depth, obtained when the tip of the cone is at that depth, represents the mean resistance through the depth increment between this and the previous reading.

Although the above equation has been commonly and universally used, and the resistance values have been correlated with other strength indices (ACFEL 1954, Abele 1963, Abele et al. 1968), the equation is a simplification of the real case and is not completely satisfactory (Waterhouse 1966).

Because of the conical shape of the penetrometer head and the proximity of a free surface, the resistance number (obtained by the above equation) for the 0- to 5-cm depth has to be multiplied by 4.7, that for the 5- to 10-cm depth by 1.6, or that for the 0- to 10-cm depth by 3, to obtain the

RAMMSONDE HARDNESS

No. ______

Location ______________________________ Test Position ______

Surface Descr. ______________________________________

Age Hard. ____________________ Snow T ______ Air T ______

Date ____________________ Time ______ Observer ______

Remarks ____

$$\text{Hardness No.} = R = \frac{Whn}{x} + (W + qQ)$$

W = Wt. of hammer (kg) — h = Height of fall (cm)

q = No. of tube lengths — n = No. of blows

Q = Wt. of one tube (kg) — d = Depth of cone

x = Penetration resulting from n blows

W	h	n	d	x	$\frac{Whn}{x}$	W + qQ	R	

Figure 5. Rammsonde data card.

true ram resistance of the 10-cm surface layer (Bender 1957, Brunke 1959, Niedringhaus 1965). The applicability of these factors to less dense annual alpine snows has not been determined.

Figure 5 shows the ram resistance data card that is used in the field. The "age hardening" entry pertains to processed or milled snow used for construction of snow roads and runways.

The standard Rammsonde kit contains extensions for the penetrometer shaft in case hardness profiles are required for more than 1 m depth.

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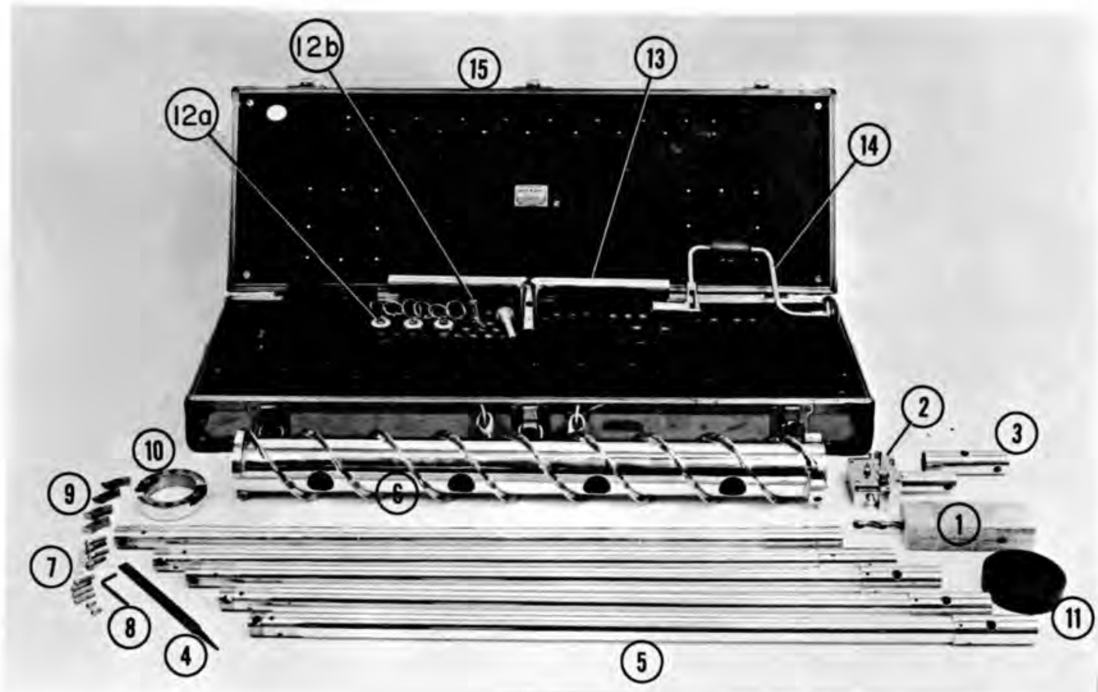
APPENDIX A

INSTRUCTION SHEET

USING THE USA CRREL 3-INCH CORING AUGER KIT

The CRREL 3 in. coring auger kit is designed for manually drilling and coring in snow or ice. With modifications, it can also be used in frozen silt. The auger produces a 4⅞-in.-diam hole and a 3-in.-diam core. Five 1-meter extensions are supplied with each kit, providing a maximum drilling capability of 6 meters (19.7 ft). Additional extensions can be used.



No.	Item	Quantity	No.	Item	Quantity
1.	Starting guide	1	8.	Socket head wrench (3/16 in.)	1
2.	Driving head	1	9.	Cutting inserts:	
3.	Adapter	1		a. Hardened steel	2
4.	File	1		b. With carbide cutting edges	2
5.	Extensions (1 meter)	5	10.	Cutting shoe	1
6.	Auger barrel	1	11.	Protective cap	1
7.	Hardware:		12.	Pins	
	a. Socket head screws (¼-20 × 1 in. long)	4		a. Quick release type b. Pivoting arm type	8 8
	b. Socket head screws (¼-20 × ⅜ in. long)	4	13.	T-Handle	1
	c. Elevating screws (¼-20 with ½-in.-diam. head)	4	14.	Auger brace	1
	d. Elevating screw washers	10	15.	Carrying case	1

Figure 1. USA CRREL 3-in. coring auger kit.

Figure 2

Figure 3

1. When assembling the driving head to the top of the auger barrel do not use excessive force on the lever arm which locks the head in place (Fig. 2). If the arm is difficult to move, always check to see if the holes in the auger are lined up to receive the pins from the driving head.

2. For coring in snow, the auger is simply placed on the surface and turned clockwise using the brace. A starting guide consisting of a wooden block and a ½ in. twist drill assists in starting holes on hard ice surfaces, or starting horizontal holes. The guide is dropped into the top of the auger barrel and pinned so that the steel twist drill protrudes from the bottom of the barrel (Fig. 3). After about ½ in. of cutter penetration, the starter can be removed.

3. Where higher torques are required, a T-bar is provided which can be used in place of the brace. Excessive torques, however, can be an indication of trouble. If in doubt, it is advisable to retract the auger, remove the core and cuttings, and start again.

4. The core length obtainable in a vertical hole in snow or ice depends upon the depth of the hole. At the start, where some of the cuttings or chips accumulate on the surface, a core nearly 3 ft long can be obtained. Beyond this depth, the core length is limited by the total auger volume available to contain the core and cuttings while not allowing any cuttings to accumulate above the barrel. A full barrel, which can sometimes be felt by a decrease in torque, is the limiting factor.

Some of the cuttings fall back down the hole during auger retraction, especially as the hole gets deeper. This results in less core and more cuttings on the following run. At moderate depths the core yield will be about 18 in. to 24 in. After the auger moves through any accumulated cuttings and reaches virgin material, the auger advance should be gaged, either by counting turns or measuring, so as not to exceed the above limits. Excessive cuttings can bridge over the top of the barrel and make auger extraction difficult and sometimes impossible.

Figure 4

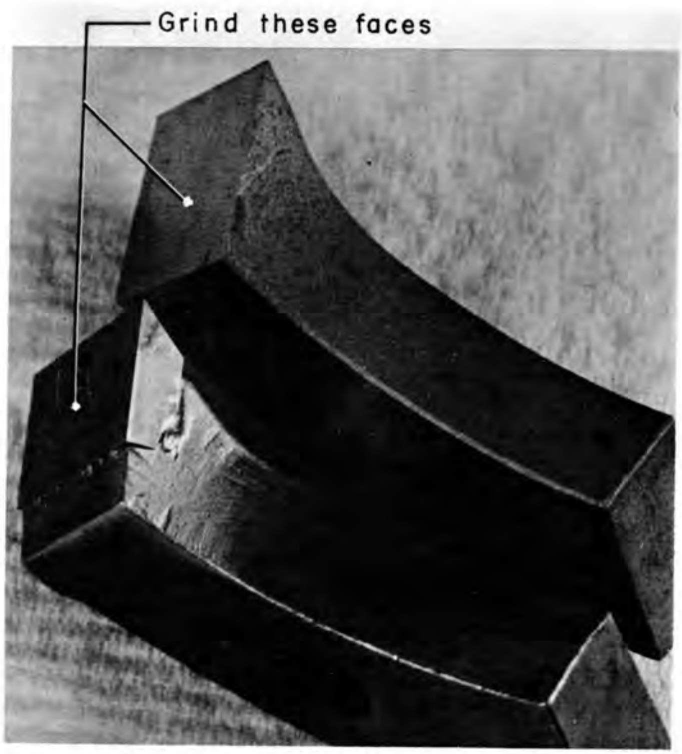


Figure 5

5. Normally, sufficient cuttings jam in between the core and cutting shoe to help break off and retain the core. A slight jarring movement at the top of the string of extensions usually assures core breakage.

The core is removed by first removing the driving head and then allowing the core to slide out of the top end of the auger barrel (Fig. 4). Sometimes a tap or push is required to start the core sliding.

6. All kits contain two sets of cutters. One set is made of hardened steel for use in snow and ice; the other set has tungsten carbide cutting edges for use in more abrasive material. When sharpening cutters it is important to grind on the front faces only. This will assure the retention of an adequate clearance angle (Fig. 5). *Worn cutters should not be discarded.* Carbide cutting edges can be replaced and worn steel cutters can be ground and fitted with carbide edges.

Figure 6

Figure 7

7. The depth of cut of the cutting shoe can be decreased by placing washers underneath the elevating screws (Fig. 6).

8. An effort should be made to keep the working and mating parts of the kit reasonably free of snow or ice chips. When augering through sea or lake ice, water will probably get into the joints and fittings and freeze. A propane torch or a squirt can containing alcohol or an aqueous ethylene glycol solution is helpful in this situation as is the use of the pivoting arm type of pin on the extensions (Item 12b, Fig. 1).

9. The protective cap should be placed on the cutting shoe to protect the cutters whenever the auger is not in use (Fig. 7).

August 1970

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APPENDIX B

INSTRUCTION SHEET

USING THE USA CRREL ICE THICKNESS KIT

The USA CRREL Ice Thickness Kit has been specially designed for rapid manual drilling and measurement of ice thickness. As an example of the ease and speed with which holes may be drilled in ice using this kit, 15 holes have been drilled and measured in 6 ft of sea ice along a 7000-ft strip in 1½ hr, including walking time. However, in fresh-water ice and old (over 1 year) sea ice thicker than the length of the auger (39 in.) the drill may stick unless proper precautions are taken.

USA CRREL Ice Thickness Kit

1. *Ice chisel*
2. *Measuring tape, with rod*
3. *Extension rods*
4. *Auger protective cap*
5. *Auger*
6. *Brace*
7. *Canvas cover*

Drilling and Measuring Procedure

1. After drilling about 30 in., pull out the drill, continuing to rotate it slowly in a clockwise direction to help retain the cuttings; clean the drill and pour about ⅓ cup of nonfreezing liquid into the hole. A number of different liquids can be used, such as gasoline, kerosene, alcohol, ethylene glycol, or de-icing fluid.

(over)

2. Continue drilling; pull the drill completely out of the hole as in operation #1 whenever it becomes difficult to turn. If the drill is not withdrawn in time, the cuttings will build up and the drill will suddenly freeze in.

3. When the hole is about 50 in. deep, add another ⅓ cup of the liquid.

4. Same as #2.

5. If the ice is very thick, you may need to add another portion of the liquid at about 70 in.

6. You may find that the drill does not bite into the ice after you have added the liquid. This may be remedied by lifting the drill about 5 in., dropping it hard into the ice, and turning it again.

7. As soon as you have drilled through the ice, pump out the slush by rapidly lifting the drill completely out of the hole several times.

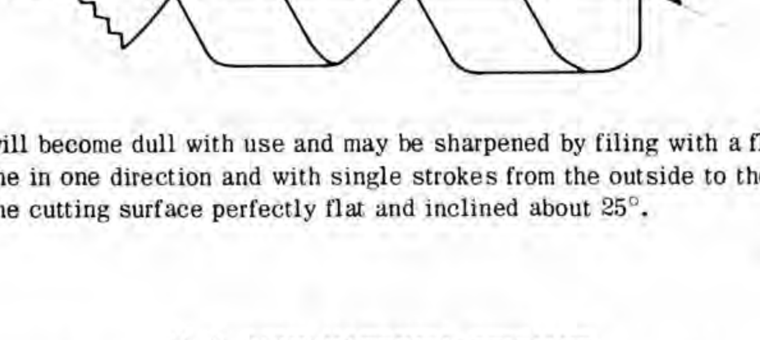
8. The extension rods should be disconnected as soon as the pumping has been completed, as water will freeze on the drill, making it difficult to disconnect the rods. If ice does form, it may be removed in some cases by a *light* tapping, or, if you have alcohol or ethylene glycol, by putting a small quantity on the joint and wiping off the slush. The button connections should always be kept free of snow and ice.

9. To measure thickness with the tape, lower the steel rod on end by holding the wire, allowing the tape to slip by and paying out the same lengths of each. Care should be exercised to prevent the wire and tape from entangling. When the rod has reached a depth of about 6 in. below the ice-water interface, pull the tape upward about 4 in., holding the wire still – this tips the steel rod from a vertical to a horizontal position. Slowly bring both wire and tape upward until the rod stops at the interface. Slack off on the wire, pull the tape taut, and read to the nearest ½ in.

10. To remove the rod and tape, lower the rod about 6 in. and pull up on the wire, holding the tape loosely.

11. An ice chisel is included in the kit to enable you to chop away the ice around the drill if it gets stuck.

Sharpening Procedure



The drill will become dull with use and may be sharpened by filing with a flat hand file. The filing should be done in one direction and with single strokes from the outside to the center. It is most important to have the cutting surface perfectly flat and inclined about 25°.

February 1968

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