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SOIL SAMPLING IN PERMAFROST AREAS

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THE OCCURRENCE of perennially frozen ground, more commonly known as permafrost, throughout much of northern Canada creates special problems for engineering construction. With the great increase in construction activity in Arctic and Subarctic regions, the difficulties encountered in both the construction and maintenance of buildings, roads, airstrips and other structures have emphasized the need for thorough site investigations prior to the design of such structures in areas underlain by permafrost.

Permafrost is not a new material but is simply the frozen equivalent of materials found in more southerly regions. It is a thermal condition of the ground, and the engineering problems associated with it arise mainly because of the variable nature of soil properties from the frozen to the thawed state. Perennially frozen ground which may contain a great deal of moisture in the form of ice may, upon thawing, lose much of its supporting strength, resulting in large settlements and even failures of various structures erected upon it.

A knowledge of the ice phase in frozen soils is most important to the engineer for it is this factor that has the greatest effect on the performance of any structure. Ice segregation may occur in many ways ranging from coatings on individual soil particles and minute hairline lenses, scarcely visible to the naked eye, to large inclusions of ice up to several feet thick. These different forms of ice segregation can and do occur in all types of soil, even in gravel and coarse sand. The most serious difficulties, however, arise from fine-grained soils in which the moisture content may be very large but where the ice segregation may be difficult to discern. All soils must be examined and sampled, therefore, to determine the form and distribution of ice in them, in addition to the soil type.

Although it is not always easy to distinguish between seasonally and perennially frozen ground, the depth of the active layer and the depth of seasonal frost penetration should be determined during the course of subsurface investigations. This is of particular importance in the region at the southern boundary of permafrost where perennially frozen ground may occur at several feet below the ground surface.

Fig. 1. Natural exposure on bank of stream—thawing occurring accompanied by slumping.

The relative inaccessibility of many northern areas and climatic limitations may dictate to a large extent what form a subsurface investigation may take. The purpose of this paper is to outline the various procedures and techniques that may be used in engineering soil surveys to obtain representative samples of perennially frozen ground in northern areas, so that subsurface conditions may be adequately determined.

Fig. 2. Natural exposure following a local slide in side of hill showing large masses or lenses of ice. Note large boulders in the predominantly fine-grained soil.

METHODS OF OBTAINING SOIL SAMPLES

Engineering soils and permafrost investigations may be carried out to depths of only 10 ft. or as much as 100 ft. depending on the purpose of the survey. Such investigations may use one or more of the following methods to obtain representative samples for the determination of soil and permafrost characteristics:

(a) sampling natural exposures,
(b) hand borings,
(c) test pits,
(d) core drilling.

The first two methods are generally applicable for shallower depths and for general information, while the last two will give detailed information to greater depths. Each method will be discussed separately. A list of equipment required to carry out each of the above methods of exploration is given in Appendix A.

Sampling Natural Exposures

Much information about soil can be gained with little effort by examining

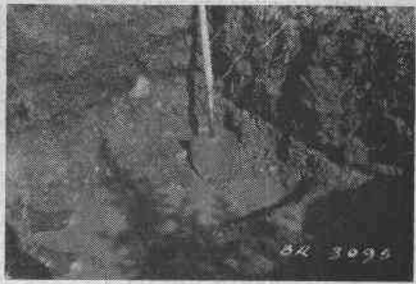


Fig. 3. Test pit excavation by natural thawing. Removing thawed material from test pit excavated in gravel.

natural exposures such as those occurring along stream and lake banks, in gullies and, as a result of local slumping, (Figs. 1 and 2) on steep, generally south-facing slopes. By late summer, thawing has usually penetrated well into the face of the exposure so that representative samples can be easily obtained.

If a complete profile of the exposure is required, colluvial material must be removed by digging a narrow trench down the slope. Deeper excavation into the slope is carried out at intervals when the soil type changes, and samples for classification and identification testing are taken. Colluvial material is usually easily recognized because it is a heterogeneous mixture of most of the soils found in the exposure. It is most easily recognized by its disturbed structure while the parent material is more orderly.

On large (deep) exposures, excavating to obtain a continuous profile is a tedious and time-consuming task. Frequently, colluvial material is only removed at the top, middle and bottom of the slope with small test pits at each of these locations. Where irregularities or distinct changes occur on the slope, additional excavation should be carried out at these points.

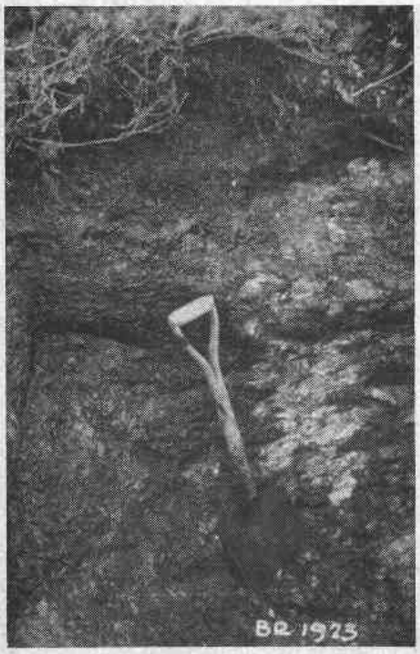
In all soil exposure excavations, the slope orientation and depth to frozen ground (at right angles to the slope) should be noted. In many cases, frozen soil may be encountered relatively close to the face of the slope and a careful examination should be made to determine the extent and types of ice segregation occurring in the material. Caution should be exercised, however, in describing the ice phase for it has been found that the ice structure in these locations is often disturbed and modified by its proximity to and the effect of the slope. If frozen soil is not encountered in the excavation, then its location with reference to the face of the slope should be established by means of probing. The expenditure of much energy to obtain frozen samples from an exposure is not usually justified.

Accepting the limitations of this method in providing reliable information on ice segregation, the investigation of natural soil exposures is still one of the most effective means of obtaining much exploratory soil information in northern areas with a minimum of effort. The method should be used wherever possible for a preliminary assessment of soil and permafrost conditions in any area under consideration as a construction site.

Hand Borings

Obtaining soil samples of perennially frozen ground using conventional hand-boring equipment is difficult and at times impossible because of its rock-like nature. Hand borings are not practicable in frozen granular deposits but may be used in fine-grained soils such as silt and clay-size materials, particularly in the more southerly areas of permafrost where these soils may not be as tightly bonded by ice as those encountered further north. All samples obtained by hand-boring equipment are generally disturbed and their usefulness is limited to identification and classification of the soils. Little information is obtained with respect to ice segregation occurring in the material. With light equipment, hand borings can produce some soil information of value in a preliminary assessment of an area.

Fig. 4. Test pit excavated by pick and shovel in fine-grained soil. Note occurrence of ice to right of shovel and also slumping and thawing of material on left side of pit.



Driving Pipe

Core samples of frozen fine-grained materials can sometimes be obtained by driving a heavy walled steel pipe into the ground with a sledge hammer. The pipe used should be about 1 to 2 in. in diameter and about 5 ft. in length. The upper or striking end of the pipe should be fitted with an extra heavy coupling or pipe cap to prevent splaying of the pipe when struck. The cutting edge of the pipe can be specially hard tipped but generally this is not warranted. The cutting edge can be kept relatively sharp using a file. As the pipe is struck, it is rotated by pipe wrenches. It should not be driven more than 6 to 9 in. into the ground at one time, since the removal of the pipe can be difficult. The soil core is removed from inside the pipe by gently tapping the outer wall with the hammer. Holes have been produced by this method to depths of about 5 ft. An indication of the type and amount of ice segregation can be gained from an examination of the cores. As would be expected, this method is time-consuming and a large amount of energy is expended to procure samples.

Hand Augering

Disturbed soil samples have been taken in fine-grained soils such as silts and clays, using small diameter (4 to 6 in.) post-hole type augers and chopping bits. The procedure is to chop the frozen material into small fragments which can then be removed with the auger. Holes have been bored to depths of 25 ft., but depths of 15 to 20 ft. are generally the maximum limit using this method. Ice or brick chisels with blades 2 to 3 in. wide have proved suitable as chopping bits. The chisel edges can be specially tipped with hard metal to give longer life. The augers should be strengthened by welding, particularly at the point of connection of the two cutting blades. The cutting edges of the chisels and the augers dull very quickly and therefore often require filing. Generally a ¾ in. nominal standard pipe has been used for the shafts of both chopping bits and augers. Extra couplings and lengths of pipe should be kept on hand. The auger can be turned by using either a T connection and cross arm on the shaft or two 18-in. pipe wrenches.

In the hand-augering method the surface vegetation is first cleared from the proposed location and the unfrozen material dug out by hand to the permafrost table. The frozen material is then chopped and removed with the auger. Surface water will, in some instances, run into the hole but this will actually assist the boring operation except in very plastic soils which may become very sticky and so prevent removal of the auger as greater depths are reached. When the ice segregation in the soil consists of distinct lenses greater than 1 in. thick, the location of these can be fairly accurately determined by noting the different sounds that occur when the auger blades scrape on the ice. Although undisturbed samples are not obtained by this method, useful information can be gained as to the types of soil encountered and the extent of frozen ground occurring in the area. Occasionally this method may be combined with the former method (driving pipe into the frozen ground before using the auger) to obtain relatively undisturbed samples.

Fig. 5. Test pit excavation by pick and shovel in granular material.

Test Pits

Test pits are excavated as part of many soil surveys to permit detailed *in situ* examinations of the materials. This method is relatively slow, and consequently can be expensive but it does provide a means of obtaining valuable information that may not be obtainable by other means. Test pits are, for example, the best means of examining frozen granular deposits. As excavation proceeds, undisturbed samples can be taken from the wall of the pit.

During the summer months, with warmer air temperatures, any test pits which take longer than one day to excavate will require some form of cribbing near the surface, particularly through the active layer. Slumping of the test pit walls is more extensive in thawing granular materials, although caving can occur in fine-grained soils.

A 4 ft. by 6 ft. pit has been found the most convenient. Cribbing can be placed to support the walls so that sufficient room remains for one man to work. When the depth of the pit exceeds 7 or 8 ft., it is necessary to set up a windlass by which a bucket can be raised and lowered to remove the excavated material. A 10 gallon gas drum with the top cut out makes a convenient size of bucket.

Safety precautions must be rigidly followed, particularly in deep pits where material falling from the walls of the pit may injure the workmen.

Fig. 6. Starting test pit using air-powered jack hammer.

Safety helmets should be worn at all times.

Three methods of advancing a test pit in frozen material are: (a) thawing by natural or artificial means; (b) excavation by hand tools; (c) excavation by power tools. The first two are generally limited to shallow depths, not greater than 10 ft.

The use of explosives in excavating test pits in permafrost has not been listed since experience is limited with regard to frozen soil excavation by this method. Some preliminary field investigations have been carried out by the author and others[1, 2] with encouraging results.

Natural or Artificial Thawing

During the summer, thawing of the frozen ground can be accomplished by natural heating, open or covered fires, steam or water jetting, or electrical heating. The rate of thaw will vary depending on the thawing medium used and the type of soil, but it is generally very slow. Natural exposure to the sun and warm air has been the method generally employed (Fig. 3). The rate of thaw varies between 3 and 7 in. per day by this means, the thawed materials being removed every day or two. Because of the slow rate of thaw test pits are usually excavated to depths not exceeding 5 ft. by this method. In addition several pits are kept in operation at a time and are visited regularly to remove the thawed material, take samples and crib the walls.

Excavation by Hand Tools

Pits are sometimes excavated using pick and shovel (Figs. 4 and 5). An average rate of excavation might be 5 ft. per day (two men, 10-hour day) but will depend a great deal on the type of soil and the calibre of the laborers. Frozen granular soils are extremely difficult, if not impossible, to penetrate by this method. It does, however, offer a convenient way of getting information to relatively shallow depths (10 ft. maximum) with a minimum amount of equipment required; this is particularly important for exploration in inaccessible areas.

Excavation by Power Tools

For more detailed soil surveys where support equipment is available, test pits can be excavated by air or gas-powered jack hammers to depths of about 25 ft. (Fig. 6). The rate of advance by this method using a two-man crew has been found to be about 7 to 10 ft. per 10-hour day. The

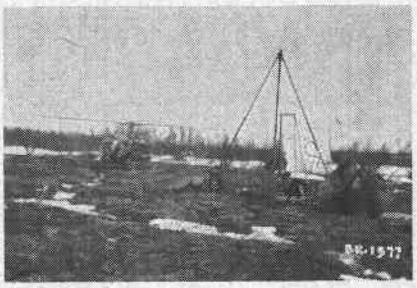


Fig. 7. Special light core drill moved to drill site by helicopter. Tent in background is used for soil sampling and photographing frozen cores.

jack hammer tools generally used are moil point, wedge and spade bits, depending on the type of soil encountered. The moil point is the most useful tool. All frozen ground dulls the cutting edges of the tools very quickly and provision therefore, should be made for sharpening on the job. A good supply of extra tools should also be kept on hand. For exploratory work, air compressors cannot always be justified or brought into the area. Self-contained gasoline-powered jack hammers which are relatively light (50 to 90 lb.) now are

Fig. 8. Standard diamond drill set-up for coring frozen soil and bedrock.

commercially available. As the pit gets deeper, care must be taken to ensure that all exhaust fumes are cleared from the pit. Flexible exhaust extension pipes can be supplied for the machine. These limit the use of this type of hammer to depths of 10 to 15 ft.

In general, the excavation of test pits in an exploratory soil survey is perhaps the most useful way of determining soils information. The amount of equipment required is not great, a most important feature when working in out-of-the-way areas. The fact that an *in situ* examination of the soils can be made as the pit is excavated, is most valuable in determining the distribution of soils and more important, the distribution of ice in the soils. From this standpoint alone, test pits should always be given top priority when setting up any site investigation program in northern areas. In granular soils, test pits are often the only practical method of obtaining detailed subsurface information.

Core Drilling

When an extensive soil exploration program is proposed for an area, or when soils information is desired at depths below 20 ft., then the work will best be carried out in most cases by means of a core drill. Good core recovery can be obtained in most frozen soils, although granular materials have proved difficult and require special techniques.[3] Stones in the soil will tend to roll around on the core bit and finally jam, preventing core from entering the barrel. In addition, bits are easily damaged when drilling in this material. The following description, therefore, applies chiefly to core sampling of frozen fine-grained soils.

The principles of drilling and obtaining frozen soil cores are similar to those of diamond drilling in rock. A power-driven rotating core barrel with a bit cuts into the frozen soil, producing a cylindrical core. The soil cuttings are carried away from the advancing edge of the bit by some fluid under pressure. This fluid, oil, air,[4] or more commonly water, travels down the inside of the drill rods and then up the sides of the hole to the surface with the bit cuttings. The frozen core is retained inside the core barrel.

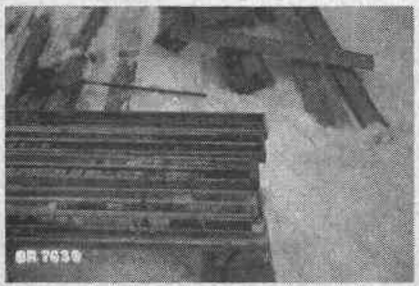
There are, however, many differences in detail and technique between drilling in frozen soil and in rock. The greatest difficulty is trying to retain the soil core in its frozen state. The ice content of most frozen soils is usually above the liquid limit of the soil, so that if the core thaws, it turns into a soil slurry and is without value for record purposes.

Equipment

Although large truck- or tractor-mounted drills have been used, excellent results can be obtained with standard diamond drills (Figs. 7 and 8). The actual size of drill used will depend on the depths to which information is desired and the size of core required, but a medium-size rig (20 to 30 hp. engine) is generally suitable. Foundation or exploratory work is rarely carried out to depths of greater than 100 ft. and in many cases, the investigations are limited to depths of 50 ft. Where supplies of fuel for the drill engine are difficult to obtain, rigs powered by diesel engines are the most economical. It is recommended that the machine be equipped with a hydraulic feed drill head rather than screw feed head; this will permit closer control of the rate of penetration through the material being cored and much faster adjustment to drilling conditions.

Because of the friable nature of the material being cored, double tube, swivel head core barrels giving cores 2 in. in diameter, (Fig. 9) or larger, are generally used.[3, 5] The core barrel most commonly used is the NX size double tube, swivel head type which drills a 3-in. diameter hole and gives a 2⅛ in. diameter core. A 5 ft. barrel length is often used. The core bits can be set with either diamond or hard metal insert-type teeth, but in fine-grained soils without any stones, best results are obtained with bits set with six carboloy teeth. The bits should be of the bottom discharge type, so that as little of the circulating fluid as possible contacts the core as it enters the inner tube at the bit, thereby cutting down on the washing action of the core.

Fig. 9. Full size (2-in. diameter) cores of permafrost showing horizontal ice segregation and variations in soil types obtained by core drilling.



The wash water pump should be a positive displacement type capable of pressures of at least 150 p.s.i. with a capacity of from 4 to 12 gpm. Single or duplex piston-type pumps are generally used, although light weight (which is important on some operations) is not a feature of this type of pump. Several 45 gallon oil drums can be used for water storage at the drill site but special canvas (or equivalent) bags (Fig. 10) of various sizes can be obtained (300 gallons or larger) for use as a reservoir.

Standard diamond drill accessories such as lifting bails, water swivels, chain tongs, etc., are required. Equipment such as a hydraulic jack should be supplied to aid in extruding the frozen soil cores from the core barrel. Casing may be required to guard against caving of the hole wall, particularly for holes 20 ft. or more in depth. Where casing is to be used, it must be drilled in and therefore casing shoe bits must be used. The casing generally freezes to the wall of the hole and must be freed by circulating warm water before it can be advanced or withdrawn.

Fig. 10. Filling 300-gallon capacity canvas bags for water supply at drill site.

Drilling Operation

A regular two-or three-man drill crew is required to carry out the mechanical operation of drilling. At all times, a notekeeper should be in attendance at the site to log the soil cores, take samples and generally supervise the operation. Drilling is usually carried out during the summer season when the air temperatures are above freezing, so that the frozen soil cores, when removed from the core barrel, thaw very rapidly, within five to 15 minutes. The cores have to be examined and logged, therefore, immediately the core barrel is brought to the surface, unless some method of refrigeration is available to preserve the cores. If a permafrost record is desired, the frozen core can be photographed on colour or black and white film. Special photographic equipment and techniques have been developed (Fig. 11) for this purpose.

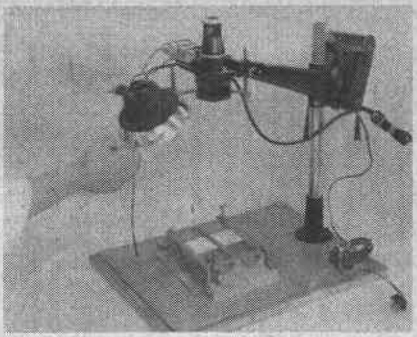


Fig. 11. Special photographic set-up for obtaining 35-mm photos of frozen cores. Cores are placed in holder on base at fixed focal distance from camera. Samples are illuminated by battery-powered strobe unit.

Perhaps the most critical factor in core drilling is the absolute necessity of maintaining close control of the wash water to obtain samples of frozen ground. Too large a volume of water tends to melt and wash away the core, while too small a volume is not sufficient to carry away the bit cuttings. Water pressure is also important because insufficient pressure will cause the cuttings to plaster along the sides of the hole and eventually jam the core barrel, preventing it from rotating. The volume of water used and the water pressure vary for different types of soil and will vary within one hole so that the driller has to adjust continually these factors to obtain good core recovery. In addition, the rate of penetration of the drill bit must be co-ordinated with the water volume and pressure.

It has been found that it takes about eight hours to drill, core and sample frozen fine-grained soils continuously to a depth of 20 to 25 ft. Under favorable conditions (short moves, good water supply, etc.) as many as three 20 ft. holes have been drilled and sampled in one day. Drilling should continue without interruption, if possible, until the hole is finished, be it 25 or 75 ft., to prevent refreezing and possible caving of the hole. Holes can be drilled to depths of 40 to 50 ft. without danger of the wash water freezing, if the water supply is at a temperature of about 50°F (even in the more northerly regions). For greater depths, however, precautions should be taken to prevent freezing.

TABLE I

APPLICATION OF SAMPLING METHODS

Method of Obtaining Soil Samples	*Type of Investigation* Preliminary	Detailed	*Type of Soil* Fine-Grained	Granular	*Depth of Investigation*	*Type of Sample* Disturbed	Undisturbed
Natural Exposures	x		x	x	No limit	x	
Hand Borings	x		x		5′—20′	x	
Test Pits—							
Natural Thawing	x		x	x	5′	x	x
Hand Excavation	x	x	x	x	10′	x	x
Power Excavation		x	x	x	25′	x	x
Core Drilling		x	x	x	No limit		x

Various methods have been used to prevent freezing: the addition of calcium or sodium chloride to the wash water, the use of Arctic grade diesel fuel, the addition of alcohol or ethylene glycol to the wash water, etc. If chlorides have been used in the wash water, then all metal parts should be carefully cleaned upon completion of the work to prevent corrosion. Small amounts of sodium chromate (1.6 lb. per 100 gallons of water) can be added to the mixture to act as an inhibitor. Arctic grade diesel fuels do not freeze at temperatures normally encountered in the frozen ground and are often readily available in the north. They are particularly good when air temperatures are low, and have been used successfully as a drilling fluid. They do tend to separate from water, however, and will allow water that may seep into the drill hole to sink to the bottom, when drilling is discontinued for any length of time and subsequently freeze there. The use of alcohol or ethylene glycol in the wash water is usually prohibitive because of cost.

Some trials have been carried out by DBR/NRC to determine the practicability of using lightweight, hand-held power drilling equipment to obtain soil cores with and without the use of wash water. These first attempts have not been too successful because of the difficulty of applying sufficient pressure to the bit so that it will penetrate the frozen soil, and because of the vibration set up by the equipment. Further trials will be made.

SUMMARY

Four methods of obtaining samples of perennially frozen ground have been described. All may be used during the course of a site investigation program, but normally one or more of the methods would be eliminated from consideration because of limitations due to the nature of the investigation, the type of soil, depth to which information is desired and/or the type of sample required.

Table I has been drawn up as a simple, but by no means rigid, guide to assist in determining the method of investigation that will give the best results for the type of information desired.

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APPENDIX A

Suggested Lists of Basic Equipment for Obtaining Soil Samples in Permafrost Areas

1. ***Natural Exposures***
   - A—Crew
     - —1 notekeeper
     - —2 labourers.
   - B—Equipment
     - —shovels
     - probe—5-ft steel bar, ¼ in. diam
     - clay pick.
2. ***Hand Borings***
   - A—Crew
     - —1 notekeeper
     - —2 labourers.
   - B—Equipment—
     - (1) Drive Pipe Sampling
       - —5-ft lengths of heavy steel pipe. (1 in. or 2 in. diam)
       - —8-lb sledge hammer
       - —10-in. files
       - —6 extra heavy couplins or pipe caps
       - —two 18-in. pipe wrenches
       - —shovels.
     - (ii) Auger Sampling
       - —4 in. or 6 in. diam post-hole type hand augers.
       - —2-in. single blade chopping bits, hard tipped
       - —three 10-ft lengths of ¾-in. steel pipe
       - —several 2-, 3- and 5-ft lengths of ¾-in. pipe.
       - —extra ¾-in. pipe couplings
       - —10-in. files
       - —two 18-in. pipe wrenches
       - —shovels.
3. ***Test Pits***
   - A—Crew
     - —1 notekeeper
     - —2 labourers
     - —1 compressor operator.
   - B—Equipment
     - (i) Hand Excavation
       - —clay picks
       - —5-ft steel bar
       - —shovels
       - —old 3-lb axe
       - —10-in. files
       - —hammer, saw, 4-in. nails
       - —pail or bailing bucket.
     - (ii) Power Tool Excavation
       - —air compressor
       - —pneumatic hammers—air or gas
       - —5 moil point tools
       - —2 spade and wedge tools
       - —5-ft steel bar
       - —shovels
       - —10-gallon gas drum
       - —50 ft of ¾-in. rope
       - —hammer, saw, 4-in. nails.
4. ***Core Drilling***
   - A—Crew
     - —1 notekeeper
     - —2 drill runners
     - —1 pumpman.
   - B—Equipment
     - —diamond drill (20 to 30 hp engine)
     - —positive displacement water pressure pump
     - —water supply pump
     - —5-ft NXL double-tube, swivel-head core barrels
     - —associated drill equipment
     - —core extruder.