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by

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BENCH MARKS IN PERMAFROST AREAS*

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Available literature on the problem of establishing reliable, permanent bench marks in permafrost areas is reviewed. The factors that influence stability are noted and some of the methods devised to provide reliable bench marks are described. Finally, the design, installation and performance of a bench mark used in the north of Canada by the Division of Building Research is described in detail.

INTRODUCTION

The establishment of reliable, permanent datum points for purposes of vertical control in permafrost areas has proved difficult. Most types of bench marks installed on regular surveys in permafrost regions are subject to movement and cannot be relied upon for any length of time. Trees, large boulders, and even foundation piles embedded to a depth of 15 to 20 ft (4.5 m to 6 m), are susceptible to movement. Marks placed in bedrock, which is not subject to frost shattering, are the most reliable, but bedrock is not always close at hand in many northern areas and bench marks must often be placed in perennially frozen ground.

It is the purpose of this paper to describe the major factors that can affect the stability of bench marks placed in permafrost and to review the types that have been used, including one installed by the Division of Building Research, National Research Council of Canada, at Inuvik, N.W.T.

FACTORS AFFECTING THE STABILITY OF BENCH MARKS IN PERMAFROST AREAS

Frost Action

The effect of frost action on the stability of bench marks becomes particularly critical in those northern areas that have a relatively thick active layer (more than 4 ft, or 1.2 m) and deep annual frost penetration. Extremely large forces can be exerted during the freezing process that will lift any structure not adequately anchored or protected against heave. Although some recovery can be expected during the thaw season, the effect over a number of years is generally cumulative. Such movements can be of the order of several inches and occur predominantly in fine-grained soils such as silts and fine sands, depending on the availability of moisture and the temperatures to which the soils are subjected. Datum points placed in well-drained soils, such as coarse sands and gravels, have been found relatively stable. Frost heave can, however, take place in these materials if they contain a large percentage of silt and fine sand.

Other Ground Movements

Movements of a lesser but still significant degree can result from the expansion and contraction caused by the annual variation of temperatures within frozen soil. It has been found that significant movements can take place down to the depth at which the annual temperature variation is about 2°F. In some northern areas this may extend to 30 ft (10 m). Areas containing patterned ground phenomena, and ice wedge polygons[1] in particular, should be treated with caution and avoided if possible. Similarly,

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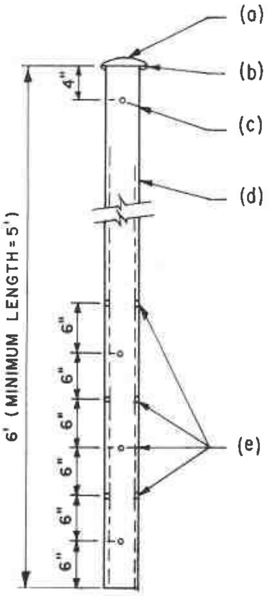
care should be exercised in areas where solifluction or slope movements are evident or suspected. Although movements attributed to these factors are rather small over short periods of time, their cumulative effect over a period of ten years or longer can be substantial.

INSTALLATION TECHNIQUES

The method of placing a bench mark in permafrost can have an appreciable effect on its future performance. Anchorage is dependent on maintaining the frozen condition of the soil, and excessive thawing of the surrounding area during installation must be prevented so that refreezing will occur as rapidly as possible. In more southerly areas where the permafrost is near the thawing point (32°F) installation procedures are particularly critical, because excessive disturbance may destroy the frozen condition and prevent its reforming.



(a) Brass marker disc, 3.5 in. (8.9 cm) dia.

(b) Brass disc brazed to pipe with continuous ¼-in. (0.63-cm) fillet weld.

(c) Hole ⅜ in. (0.95 cm) dia. drilled through both sides.

(d) Galvanized wrought iron or brass pipe, 2 in. (5.04 cm) I.D. and 2.38 in. (6.04 cm) O.D.

(e) Hole ⅜ in. (0.95 cm) dia. drilled through both walls (to permit escape of water).

FIG. 1. Detail of U.S.C.G.S. survey marker. Markers are placed in steamed holes.

REVIEW OF PAST EXPERIENCE

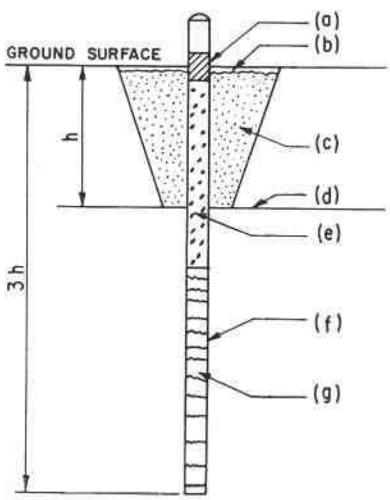
Several types of bench marks have been used by American, Canadian and Soviet agencies and observations of their performance over a number of years have been reported. A brief review of the various types is presented in the following paragraphs. Additional and more detailed information may be obtained from the references listed at the end of this article.

The U.S. Coast and Geodetic Survey has conducted investigations in Alaska[2] to determine the stability of triangulation points set in permafrost in the Point Barrow area. The type of bench mark used in shown in figure 1. These were placed in steamed holes up to 6 ft (1.8 m) deep and no protection against frost heaving was provided. It was found that the horizontal movement of these points was small, the maximum being 0.05 ft (1.5 cm) and the average 0.04 ft (1.2 cm), and that they could therefore be used for establishing horizontal control of usual accuracy. Excessive vertical movements of as much as 0.50 ft (15 cm) were observed, which restricted their use as datum points for accurate vertical control. Observations of movements of these bench marks are continuing.

The Geodetic Survey of Canada established bench marks along the Hudson Bay Railway[3,4] in northern Manitoba in 1939 by placing reinforced concrete piers in holes 5 ft (1.5 m) deep and about 5 ft (1.5 m) in diameter that were blasted out of the frozen ground. The natural moss cover was carefully removed prior to blasting and replaced after the monument was set in place. Dry moss to a depth of 3 ft (1 m) was added to provide additional insulation. No record of the performance of these bench marks is available.

Soviet experience has varied from a bench mark constructed of a pile of stones or wood placed on the ground surface[5] to embedment in perennially frozen ground of a pipe within a protective casing to a depth equal to about three times the depth of the active layer[6]. This design is similar to that used by the U.S. Geodetic Survey at Point Barrow (figure 1). Recently rather detailed studies[7] have been made to provide information for the design of bench marks protected against frost heave. As a result, the use of the bench mark shown in figure 3 was recommended. The investigations showed that to combat frost action effects the bench mark rod should extend to a depth of about 16 ft (5 m) and should be protected by a casing from the ground surface to the concrete anchor block at the bottom.

Black[8] suggests that in the Arctic coastal plains (Alaska) bench marks should be placed to a depth of 66 ft (20 m) and have a protective casing for the full depth. His requirement that the soil need be removed from only the upper 33 ft (10 m) of the casing can be questioned, however, for if any frozen soil exists between the bench mark rod and the casing any movement of the casing will be transmitted to the rod.

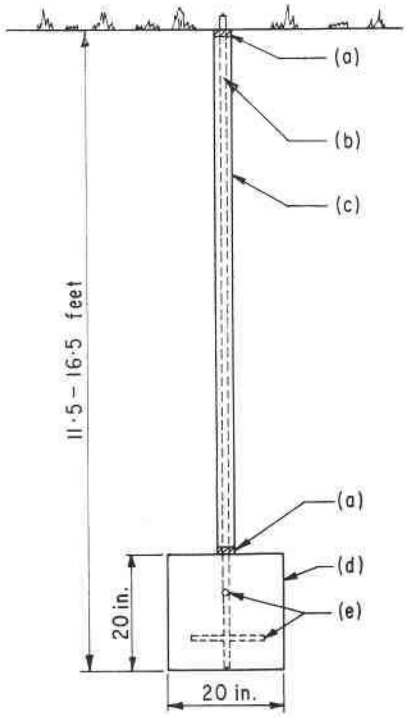


(a) Peat.
(b) Material not specified (assumed insulation).
(c) Dry sand.
(d) Permafrost table.
(e) Material not specified.
(f) Iron pipe, perforated at base.
(g) Ice.

FIG. 2. Russian type bench mark.

AFTER BYKOV AND KAPTEREV

Early studies by the U.S. Army Corps of Engineers in Alaska, reported by Guesmer[9], included observations on pipes placed up to 40 ft (12 m) in the ground by steaming and drilling. In the test areas where the permafrost table was encountered from 2 to 10 ft (0.6 to 3 m) below the ground surface, the studies indicated that pipes embedded from 18 to 20 ft (5 to 6 m) below the ground surface would provide a relatively stable vertical control point. Further investigations by the Corps of Engineers[10] have been carried out to determine the suitability of a "non-heaving"



(a) Collar between casing and bench mark pipe (to prevent entrance of water).

(b) Bench mark pipe–dia. = 2.5 in. (6.4 cm).

(c) Casing–dia. = 3.5 in. (8.9 cm).

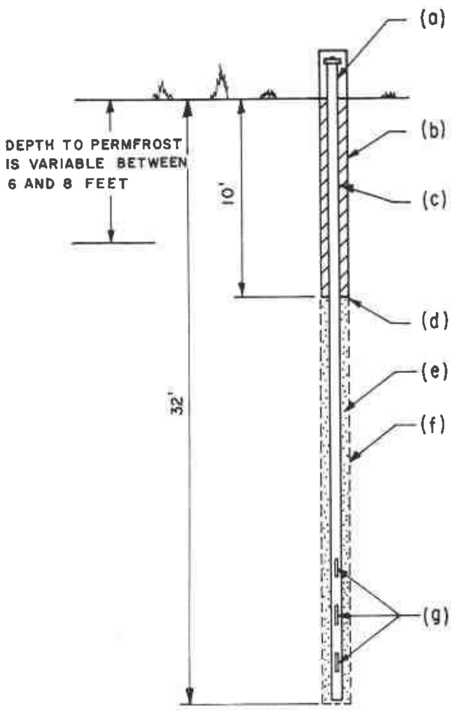
(d) Concrete anchor block.

(e) Pipe cross arms.

FIG. 3. Russian type bench mark.

AFTER USPENSKY

bench mark (figure 4) consisting of a 10-ft (3-m) length of protective casing around the main bench mark pipe. Bench marks of this type were placed in drilled holes to depths of about 30 ft (9 m) at Fairbanks, Alaska. It is believed that they will prove to



(a) Pipe, 2 in. (5.04 cm) dia., with cap and bronze bead.

(b) Casing, 4 in. (10.2 cm) dia.

(c) Heavy grease.

(d) Bottom of casing.

(e) Silt slurry backfill.

(f) Wall of drill hole.

(g) Slots, ¼ in. by 12 in. (0.6 X 30.5 cm), at 2 ft (0.6 m) o.c. (to provide adfreeze bond).

FIG. 4. U.S. Army Corps of Engineers "non-heaving" bench mark, Fairbanks, Alaska.

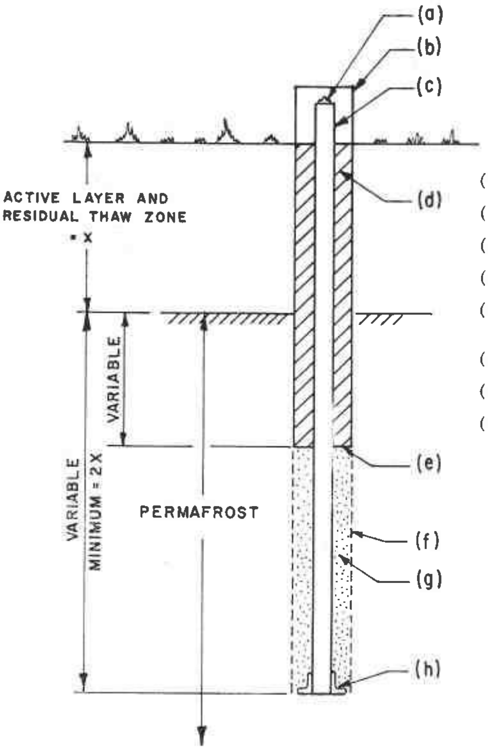
FROM ACFEL REPORT NO. MP 17

be relatively stable, for the protective casing should nullify the effects of frost action in the active layer. Further observations are continuing. As a result of these studies the Arctic Construction and Frost Effects Laboratory of the Corps of Engineers recommended in 1957 the following criteria for bench mark installations in permafrost areas:

(1) A protective casing should extend to a nominal depth into the permafrost. A flange is desirable on the outside of this outer pipe, at the bottom, to limit the upward movement of the casing.

(2) The bench mark rod should penetrate permafrost to a depth equal to at least twice the thickness of the annual thaw zone.

(3) The annular space between the casing and the rod should be filled with a material such as grease or an oil-wax mixture for the full length of the casing.



(a) Pipe plug.
(b) Outer casing.
(c) Standard pipe, 2 in. (5.04 cm) dia.
(d) Oil-wax mixture.
(e) Bottom of casing (small flange desirable on outer casing if clearance in hole permits).
(f) Wall of drill hole.
(g) Soil slurry backfill.
(h) 2 in. pipe floor flange.

FIG. 5. Permanent type bench mark recommended by A.C.F.E.L. U.S. Army (C. of E.)

FROM ACFEL REPORT NO. MP 17

Their recommended design for a bench mark is illustrated in figure 5.

More recently, however, they suggest that better criteria for the depth of embedment are:

(1) The casing should extend into permafrost to a depth where the annual range of temperature variation is about 2°F (a minimum depth of 10 ft, or 3 m).

(2) The bench mark rod need extend into permafrost below the bottom of the casing only for a distance sufficient to provide adequate support for the rod.

BENCH MARK DESIGN AND INSTALLATION

From the preceding review of literature it can be seen that in order to establish a reliable bench mark in permafrost two main requirements must be considered. First, in order that the bench mark rod may be isolated or free from the effects of frost action a protective casing should extend at least to the permafrost table. Second, the bench mark rod must be adequately anchored in permafrost at a depth below which the annual temperature variation is less than 2°F. This varies from one location to another and because of the lack of ground temperature data must usually be predicted or assumed for the area under consideration. Protective casing should extend into the perennially frozen ground so that the bottom of the casing is at least 2 to 3 ft (1 m) below the 2°F depth of annual temperature variation.

For most northern locations the protective casing should be placed to a depth of about 30 ft (10 m) and the bench mark rod extend below the casing for at least 5 ft (1.5 m). Additional anchorage can be provided by fitting flanges to that length of the rod below the casing. A flange can also be fitted to the bottom of the casing if the borehole is of sufficiently large diameter. These depths of embedment are probably conservative, but until more corroborative data are available it is suggested that they provide a useful rule of thumb. The space between the casing and the bench mark rod should be free of ice or soil and should preferably be filled with grease to allow freedom of movement between the two pipes, since the casing will generally be subjected to frost heaving forces.

Dry augering of holes creates the least disturbance of frozen soil and permits a more rapid freeze-back of the backfill material than steam thawing or drilling methods. This is particularly important in the more southerly areas where permafrost is near the thawing point (32°F) and steam thawing of a proposed bench mark location may destroy the frozen condition so that it will not reform or will reform only slowly. Often, because of the presence of stony soil, wash boring or core drilling may be the only method suitable. In more northerly areas steaming can provide a quick, efficient method because refreezing of the thawed material will take place fairly quickly—within one or two months. It has been found, however, that placing bench marks in drilled holes is generally the most satisfactory method.

Care should be taken to locate bench marks away from potential thawing influences such as buildings, roads, and streams. Sufficient time, depending on the excavation methods and the location, must be allowed for the installations to refreeze solidly before elevations can be established on the bench mark. The refreezing period can vary considerably but will certainly be a minimum of two months.

BENCH MARK INSTALLATION AT INUVIK, N.W.T.

General

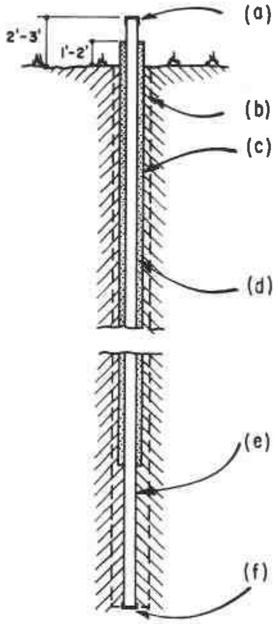
In carrying out a program of permafrost investigations at the townsite of Inuvik in the Western Arctic, the Division of Building Research of the National Research Council designed special bench marks to provide reliable vertical control. Three of these were placed in drilled holes to a depth of 50 ft (15 m) in August and September 1959, and their design and installation are described in the following paragraphs.

The soils in the Inuvik area vary extensively and include deposits of organic material up to 10 ft (3 m) thick, fine-grained soils, and deep deposits of very stony glacial tills and gravels. In general, the townsite is underlain by gravelly materials with an organic cover ranging from 12 to 48 in. (30 to 120 cm) thick. Extensive ice segration has been observed in all soils on the site. It consists mainly of thin lenses up to 1 in. (2.5 cm) thick, but in the gravels it occurs as coating on individual particles as well. Massive ice inclusions up to 8 ft (2.5 m) thick have been encountered in some areas.

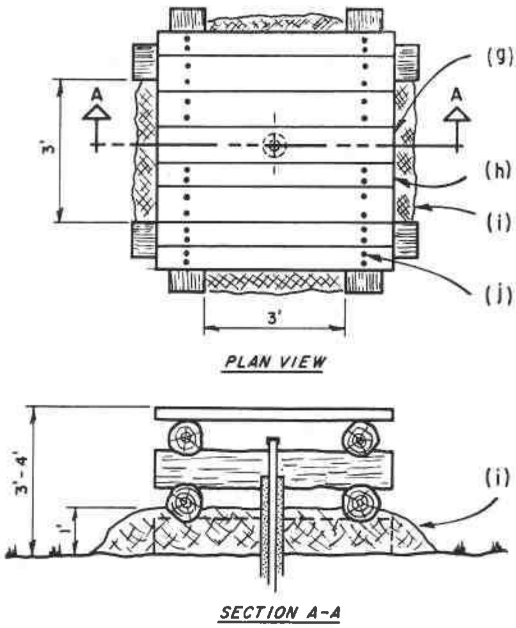
Although no actual measurements have yet been made, it is believed that permafrost extends to a depth of several hundred feet in the Inuvik area. The depth to which annual freezing and thawing occurs (active layer) varies from 1 to 4 ft (0.3 to 1.2 m) but would average about 18 to 24 in (46 to 61 cm). Annual ground temperature variations of about 10 F degrees have been observed at a depth of 15 ft (4.6 m) below the ground surface in undisturbed areas.

Design of Bench Mark

Bench marks had to be installed in drilled holes because of the very stony soil. Each consisted of five coupled lengths of black iron pipe 10 ft (3 m) long and 1 in. (2.5 cm) in diameter, placed to a depth of about 50 ft (15 m) inside four coupled lengths of black iron pipe each 10 ft (3 m) long and 2 in. (5.1 cm) in diameter. The annular space between the casing and the bench mark rod was filled with a special wax-oil mixture. Details of the installation are shown in figure 6.



Cross section of bench mark.



Protective timber crib.

(a) 1 in. (2.54 cm) pipe cap.

(b) NX hole.

(c) 2-in. (5.08 cm) standard black pipe.

(d) Wax-oil mixture.

(e) 1-in. standard black pipe.

(f) 1-in. pipe cap.

(g) Removable plank.

(h) 2-in. (5 cm) plank cover.

(i) Moss.

(j) 4-in. (10 cm) spikes.

Fig. 6. Inuvik primary bench mark installation.

Anchorage for the bench mark rod was obtained over the lower 10 ft (3 m) that extended below the bottom of the casing. A pipe cap closed each end of the rod. The upper end protrudes about 2 to 3 ft (approximately 1 m) above the ground surface and is about 1 ft (30 cm) above the top of the casing. The installation is protected from damage by a timber crib and from thawing by additional moss placed in the crib on the ground surface.

Choice of pipe sizes was dictated largely by the available drill equipment at the site. The drill casing used was NX size, the casing coupling having an inner diameter of 3 in. (7.62 cm). The largest pipe coupling that will pass through this casing is 2 in., which has an outside diameter of 2.76 in. (7.01 cm). The inside diameter of the 2-in. pipe is 2.067 in. (5.24 cm), which will allow a 1-in. pipe coupling, with outside diameter of 1.576 in. (4.00 cm) to be inserted through it. Therefore 2-in. diameter pipe was selected as the protective casing and 1-in. pipe for the actual bench mark rod.

In order to be sure that any effects from ground movements would be absent or negligible, it was decided that the bottom of the rod should be placed at a depth of 50 ft (15 m). The 2-in casing extending to a depth of 40 ft (12 m) from the ground surface would thus isolate the bench mark rod from contact with the soil through the "critical" zone. The lower 10 ft (3 m) of the rod in actual contact with the soil would have adequate support and should not be affected by movements after refreezing.

As suggested by the U.S. Corps of Engineers Arctic Construction and Frost Effects Laboratory, the annular space between the casing and the bench mark rod was filled with a special mixture of wax and oil. The oil used was Mentor 29 and the wax was a Socony Mobile Cerise AA. Other products having similar properties are, of course, suitable.

Both the wax and oil were heated to about 200°F and were then mixed in the proportion 70 per cent oil to 30 per cent wax by weight. A 10-ft (3-m) length of 1-in. diameter rod was placed inside a 10-ft length of 2-in. pipe and the space between the two filled with the mixture and allowed to harden. The 10-ft lengths of pipe were then carried out to the bench mark location and coupled together as they were lowered into the hole.

INSTALLATION OF BENCH MARKS

The holes were drilled with a medium sized diamond drill. Coring was attempted but was not too successful because of the many stones that caused extensive damage to the core bits. Thus most of the depth was drilled with a non-coring fishtail bit. As drilling progressed, NX casing in increments of 2 to 4 ft (0.6 to 1.2 m) was placed to the bottom of the hole to keep it open.

When the hole had been completed to a depth of about 52 ft (16 m) and the drill casing placed to about 50 ft (15 m) all water was bailed out. The bench mark pipes were lowered inside the drill casing in 10-ft lengths and coupled together. The drill casing was then removed. When all of it had been pulled from the hole, the 1-in. bench mark rod was positioned so that it extended about 1 ft (0.3 m) above the 2-in. pipe casing. As the drill casing was removed, the walls of the hole caved in around the bench mark pipes. Additional material was added to fill the hole around the pipes at the ground surface. A protective timber crib was then erected around the bench mark and the ground surface covered with an additional 12 in. (30 cm) of dry moss to provide further insulation.

PERFORMANCE OBSERVATIONS

Elevations were established on each of the bench marks by means of a level survey in September 1959. A more precise survey was made in August 1960 in which all level circuits were adjusted for closure errors. The elevations established by these two surveys cannot be reliably compared, however, because of the difference in precision of the two surveys and because refreezing of the soil around the lower end of the bench mark rod may have caused some slight movement to occur during the freeze-back period, when the first survey was made. Upon comparing the elevation differences, however, the largest discrepancy noted was 0.03 ft (0.91 cm). The distance between the top of the casing and the top of the bench mark rod at each installation was also noted on both surveys and the largest movement observed was 0.005 ft (0.15 cm). Continuing observations will be carried out over the next few years so that their long-term performance can be assessed.

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