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Improving electric grounding in frozen materials

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This study shows that resistance to ground of a simple vertical electrode in frozen fine-grained soil can be lowered significantly by placing it in a hole backfilled with a conductive soil-salt mixture. These tests were performed near Fairbanks, Alaska, in perennially frozen silt. Three electrodes were installed in holes created by detonating standard military shaped charges placed at the ground surface. The backfill contained varying amounts of salt. Measurement of resistance to ground of each electrode was made seasonally. The resistance to ground was lowered by an order of magnitude by the addition of

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20. Abstract (cont'd)

a water-saturated salt-soil backfill. Improvement persisted six months after the backfill was placed and allowed to freeze. The degree of improvement provided by this technique will be a function of grain size and permeability of the surrounding soil.

PREFACE

This report was prepared by A.J. Delaney, Physical Science Technician, of the Snow and Ice Branch, Research Division, P.V. Sellmann, Geologist, of the Geotechnical Research Branch, Experimental Engineering Division, and Dr. S.A. Arcone, Geophysicist, also of the Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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IMPROVING ELECTRICAL GROUNDING IN FROZEN MATERIALS

by

A.J. Delaney, P.V. Sellmann and S.A. Arcone

INTRODUCTION

An effective low resistance electrical ground for power and communications systems in the Arctic is often difficult to obtain because of the resistive nature of frozen soil. Earth electrode resistance is highly variable, being dependent on the number and configuration of electrodes used, soil type, moisture content and temperature. The last two variables can cause seasonal variations in resistance after an electrical ground is installed.

The available literature on arctic grounding procedures is not extensive. Arcone (1977) presented numerical calculations of the resistance to ground of horizontal and vertical rods placed in a two-layer ground model. The results verified the obvious fact that good grounding requires the rods to be emplaced in the most conductive zones. Hessler and Franzke (1957) demonstrated the effectiveness of salt in lowering the wintertime high resistance to ground of electrodes buried in the shallow active layer above permafrost near Barrow, Alaska. Recommendations for improving electrical grounding for military operations are presented in a report prepared by the U.S. Army Engineer District, Alaska (1973).

Grounding problems on extremely large northern and arctic engineering projects (including construction of pipelines and oil fields, mining operations, and development of communities) can usually be resolved, even in areas of thick permafrost, through careful site selection studies (Sellmann et al. 1974, Nozhevnikov 1959). The resolution of such problems depends on finding the zones of low resistivity that can occur locally in permafrost terrain.

Development of effective, expedient methods of improving grounds during smaller scale northern projects, including military operations, can be more difficult because moving to a more suitable grounding site may not be practical. Therefore, when highly resistive frozen ground cannot be avoided, mechanical assistance and chemical modification of the soil may be required to facilitate electrode installation and to lower the resistance to ground. In areas of seasonal frost and in some permafrost areas with more conductive thawed soils at depth, development of an effective ground requires only mechanical assistance (excavation, driving or drilling) for gaining access to the thawed material.

This report discusses an experimental technique for developing improved grounds by 1) using a shaped charge to make a hole for electrode emplacement, and 2) modifying the soil by addition of salt to the backfill to improve the electrical properties of the soil.

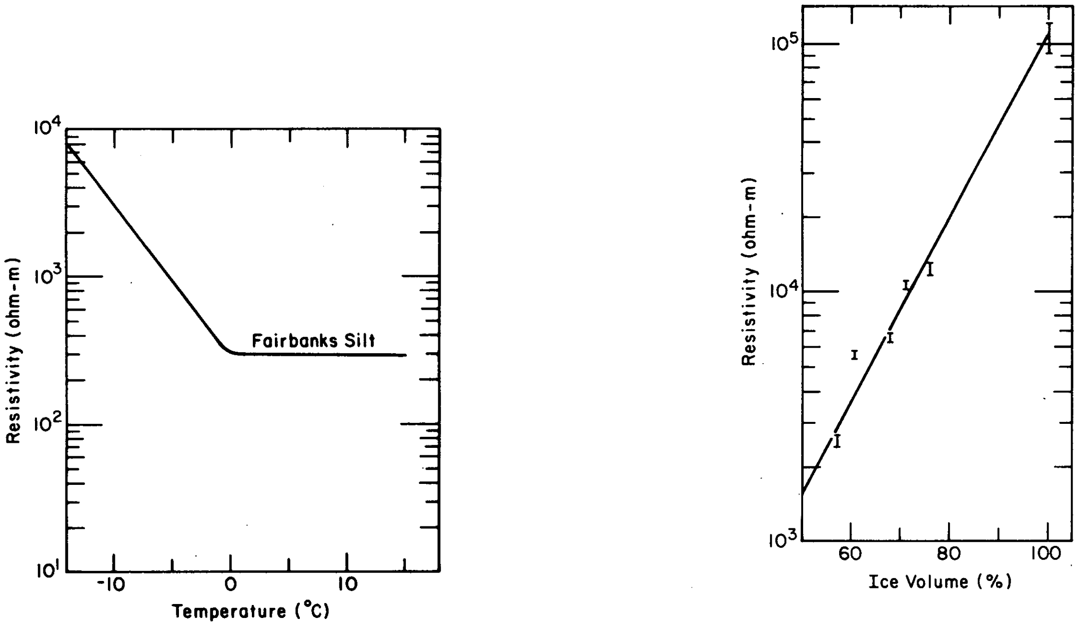
OBJECTIVE

The objective of this investigation was to determine the effectiveness of a salt-soil backfilled hole produced by a standard 6.8-kg (15-lb) military shaped charge for lowering the resistance to ground of a single vertical electrode placed entirely in frozen soil. Performance of the ground was determined seasonally to evaluate the influence of temperature changes below 0°C and the effect of freezing on the salty backfill.

To meet this objective, four electrodes were installed in perennially frozen silt at Ft. Wainwright, Alaska. Three of the electrodes were emplaced in holes produced by shaped charges. The fourth "control" electrode was driven into frozen ground for comparison purposes. The backfill used in two of the shaped charge holes was a salt-soil mixture. The electrical resistance of each electrode was measured during the fall and spring.

SITE DESCRIPTION

The test site was located on a northwest-facing hillside in a remote section of the Ft. Wainwright military reservation. The area is covered by dense black spruce-birch forest with an organic active layer that seasonally thaws down to about 70 cm. The mean annual air temperature is -3.2°C (U.S. Weather Bureau 1943). This site is typical of the permafrost terrain in much of the Yukon-Tanana Uplands. The perennially frozen soil at this site is ice-rich silt to organic silt (Williams et al. 1959, Sellmann 1967). The d.c. resistivity of this material as a function of temperature



a. Resistivity of saturated Fairbanks silt vs temperature.

b. In-situ resistivity vs ice content of Fairbanks silt as measured in the wall of the CRREL Permafrost Tunnel.

Figure 1. d.c. resistivity of saturated Fairbanks silt as a function of temperature and ice content (after Hoekstra et al. 1974).

and ice content is shown in Figure 1 (Hoekstra et al. 1974). Typically, permafrost just below the active layer in this area has temperatures a few tenths of a degree below 0°C in mid-September and about -2°C in mid-April when our measurements were made. Below the active layer, the silt has very little organic content. These material properties would correspond to a resistivity of about 200,000 ohm-cm in mid-April and about 60,000 ohm-cm in September.

METHODS

The fall-of-potential method used to measure the electrode resistance is described by Tagg (1964). The electrode "E" under test is one element of a three electrode array as shown in Figure 2. A known current I is passed between electrodes E and C. Electrode C is a fixed distance from E, great enough to remove C from the influence of E. The induced voltage V between electrodes E and P is then measured as electrode P is moved along the line between E-C. The resistance to ground of electrode E is determined simply from the slope of the V/I vs P-E separation in the central

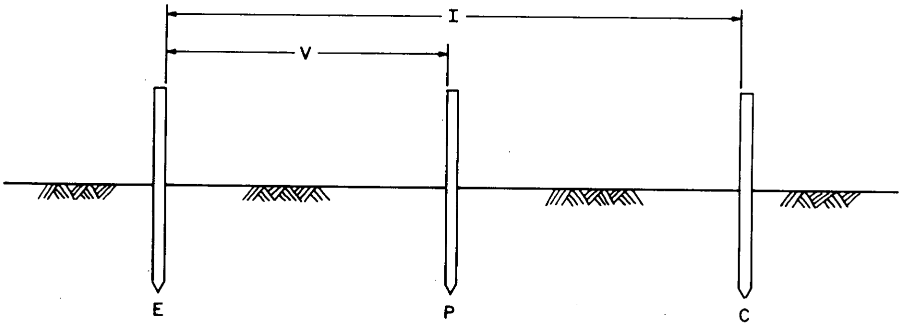


Figure 2. Electrode configuration used to determine resistance to ground.

region of the curve where the influence of electrodes upon each other is negligible. For a single vertical electrode the true resistance is theoretically obtained when distance P-E equals 61.8% of the distance E-C.

A low frequency a.c. signal is used for a current source to avoid electrode polarization. Voltage measurements are made with a high input impedance meter.

ELECTRODE INSTALLATION

The test electrodes were installed in September 1980 when the active layer was thawed. At this time of year grounding is not normally a problem because of the conductive surface layer. However, since we were only interested in grounding characteristics of the frozen material, we removed the thawed material near the electrodes to simulate frozen ground conditions. Therefore, the seasonal variations observed were due mainly to changes in temperature of the frozen soil.

Standard ground rods of copper-clad steel, 1.6 cm in diameter and 2.0 m long, were used. The control electrode was driven 40 cm into the permafrost. The remaining three electrodes were installed in holes produced by detonating standard military 6.8-kg (15-lb) shaped charges at the ground surface. No charge standoff was used since the thawed active layer provided the appropriate separation from the frozen sediments at depth. The electrodes were then placed in the small-diameter holes produced in the frozen ground which were backfilled with thawed silt picked up from the surrounding area. Two of the holes had salt and water added around the electrode while backfilling. The larger surface crater formed in the thawed active layer down to the frozen material was backfilled after the test with expelled surface debris, including fragments of the moss mat, to prevent accelerated thaw of the permafrost.

Data available in Mellor and Sellmann (1970), and Benert (1957, 1963) suggest the depth and range of hole sizes that are produced with shaped charges for various material types. Figure 3 shows penetration depth data as a function of charge weight from Benert's experiments. Figure 4 shows the range of hole depths and sizes produced with 6.8-kg shaped charges in common frozen materials (Mellor and Sellmann 1970). Even though these holes were not produced with the standard military 6.8-kg charge, it can be seen by comparing Figures 3 and 4 that the performance characteristics are similar. A typical crater resulting from detonation of an M2A3, 6.8-kg charge in frozen silt with a thawed active layer at our study site is shown in Figure 5. Data for the electrode installation are given in Table 1.

RESULTS

A single vertical control electrode was driven 40 cm into the silt to refusal. The resistance to ground of this electrode (electrode 1) was measured in September and again in April when the ground temperatures were lower and the active layer was completely frozen. The data are plotted in Figure 6. The "true" September resistance was about 1200 ohms, while the colder (frozen) ground in the spring increased this to about 1500 ohms. In either case, the values are unacceptable for grounding purposes.

Electrode 2 was installed in a hole in frozen material created by detonating a 6.8-kg shaped charge. The hole was 190 cm deep with an average radius of 4.0 cm. This electrode was backfilled with saturated silt.

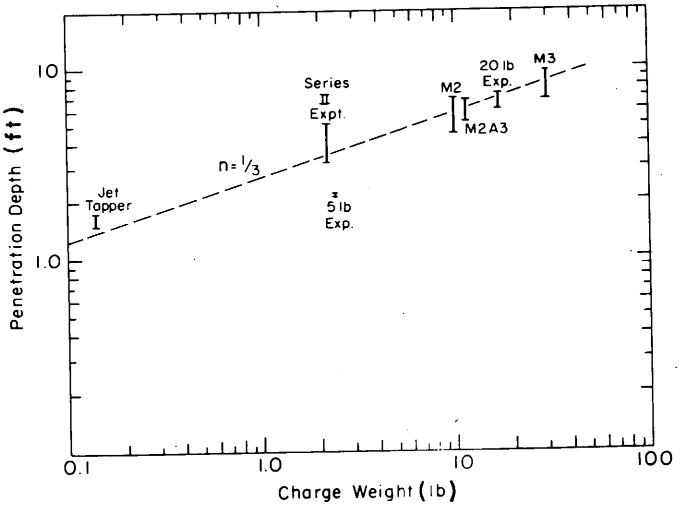
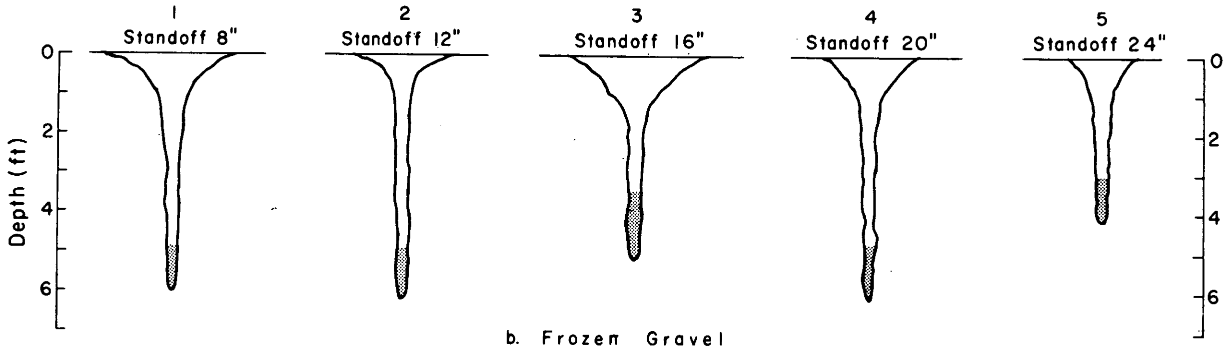
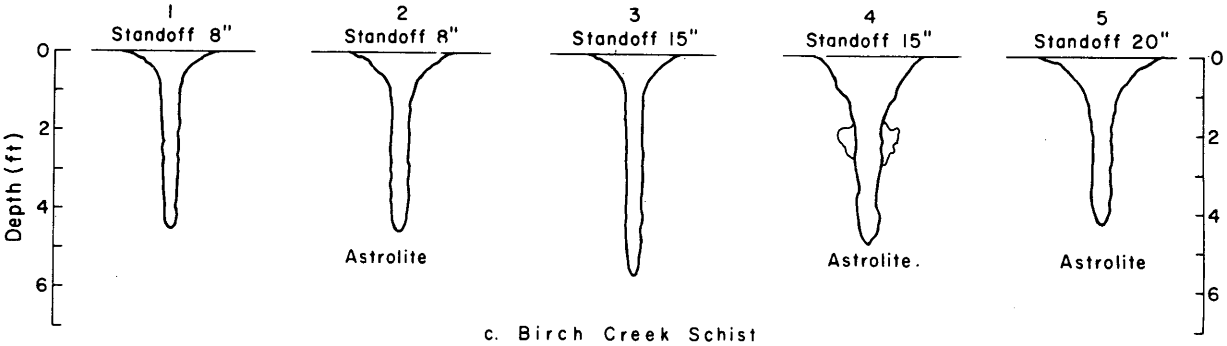


Figure 3. Penetration depth as a function of charge weight for shaped charges penetrating frozen ground (data from Benert 1957, 1963).

a. Frozen Silt



b. Frozen Gravel



c. Birch Creek Schist

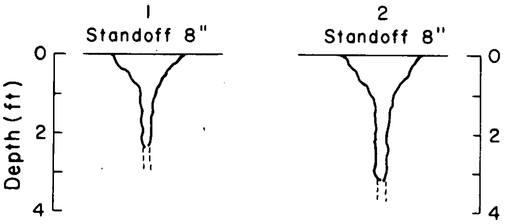


Figure 4. Shaped charges (6.8 kg of nitromethane unless otherwise noted, 60° cone, 22.8-cm O.D.) in frozen silt, frozen gravel and Birch Creek schist.

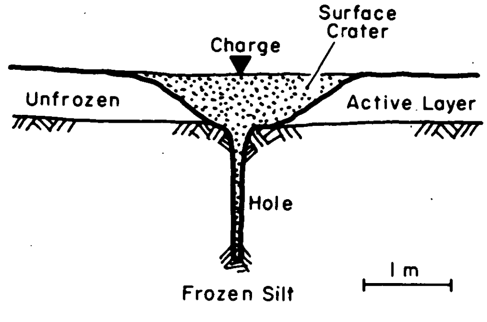


Figure 5. Typical crater and hole resulting from detonation of an M2A3, 6.8-kg shaped charge at the ground surface.

Electrode 3 was installed in a hole nearly identical to the one in which electrode 2 was placed. The only difference was that 4.5 kg (10 lb) of fine table salt and 3.8 L (1 gal.) of water were mixed fairly uniformly into the backfill. Measurements of electrode resistance were made 24 hr after installation.

Table 1. Information on electrode installation.

Electrode		Installed depth (m)	Hole diameter (cm)	
1	Driven	1.0	na	Rod driven into frozen silt
2	M2A3	1.9	8.0	Modified thawed silt and water backfill
3	M2A3	1.9	8.0	Modified 4.5 kg of salt with thawed silt and water backfill
4	M2A3	1.4	8.0	Modified 2.3 kg of salt with thawed silt and water backfill

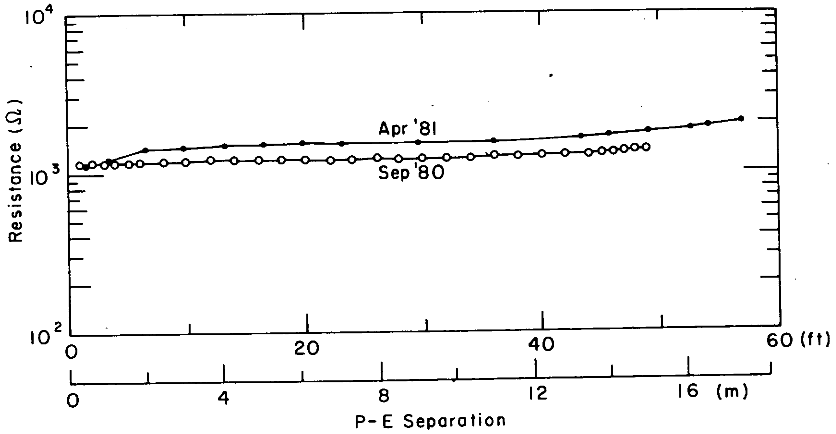


Figure 6. Resistance to ground of electrode 1 measured in September 1980 and April 1981.

Electrode 4 was installed in the same manner, with 2.3 kg (5 lb) of salt added to the backfill.

Figure 7 compares the resistance to ground of the driven control electrode with the resistances of electrodes 2, 3, and 4 that were installed in holes produced with shaped charges. All these measurements were performed in September 1980. The effect of placing electrode 2 in a hole backfilled with saturated silt was to lower the resistance to 230 ohms, a significant improvement compared to 1200 ohms for the driven electrode. This improvement was mostly due to the increased electrode effective diameter, which now corresponds approximately to the diameter of the hole filled with the extremely conductive saturated thawed silt. The effect of adding salt to

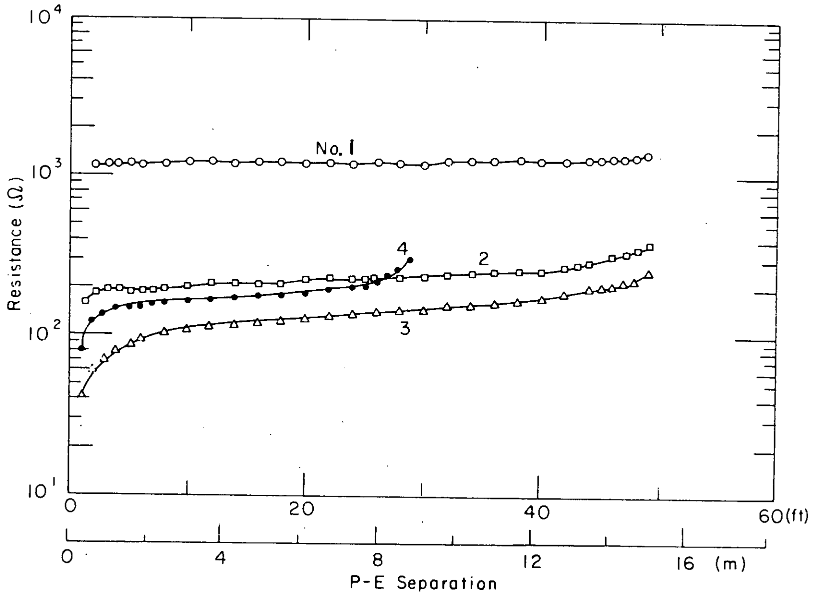


Figure 7. Resistance to ground of electrode 1 compared to that of the three modified electrodes. All measurements were made in September 1980.

the backfill is shown in Figure 7 by the curves for electrodes 3 and 4, where the "true" resistance (electrode 1) was lowered to 140 and 180 ohms, respectively.

The resistance to ground of electrode 3 was remeasured in April 1981 when the entire ground was frozen, and the results are compared in Figure 8 with those of the previous fall. The resistance to ground increased from 140 ohms to 360 ohms over one winter.

The most meaningful comparison is between the control and the salted electrodes after winter freezeback, as shown in Figure 9. The lasting influence of the salt can be seen with a resistance to ground of 360 ohms. The resistance to ground of the driven rod in natural terrain was 1500 ohms.

It was not possible to test electrodes 2 and 4 in the spring because they were located in a low area, and water from an early spring rain had accumulated in their surface craters.

DISCUSSION

In theory (Tagg 1964), the resistance to ground for a single vertical electrode of length ℓ (in the earth) and radius α, emplaced in homogeneous soil of resistivity ρ(ohm-cm), is found from

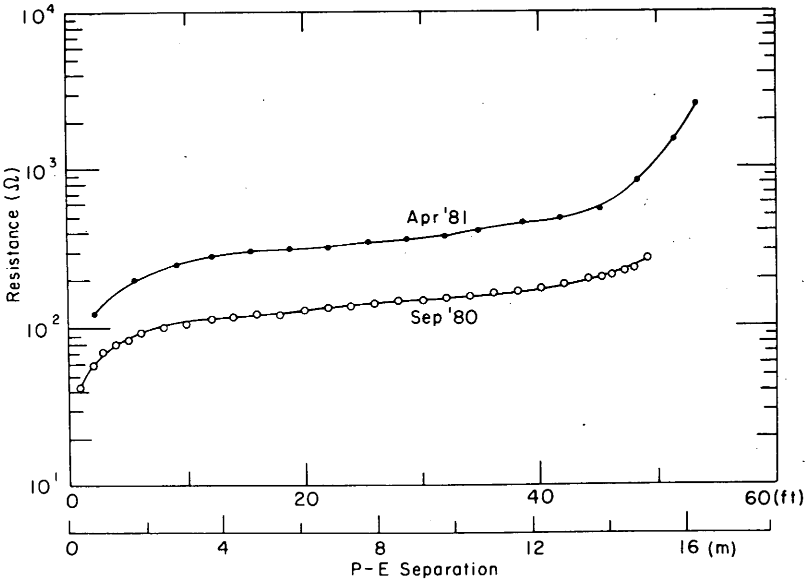


Figure 8. Resistance to ground of electrode 3 for two seasons.

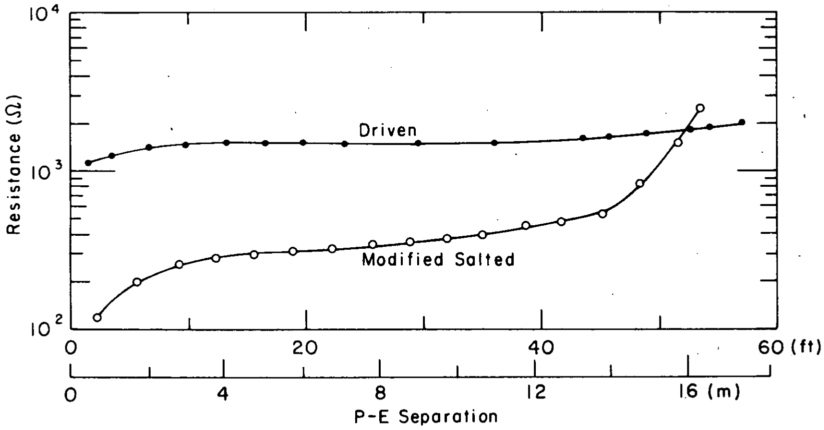


Figure 9. Resistance to ground of electrodes 1 and 3 after winter freezeback.

$$R(\text{ohms}) = \frac{\rho}{2\pi\ell}\left[\ln\frac{4\ell}{\alpha} - 1\right] \quad .$$

By using the value ρ = 60,000 ohm-cm for September, as discussed above, this formula gives 1027 ohms for a single 1.6-cm-diam. electrode driven 40 cm into frozen silt. This value is close enough to the measured September value of 1200 ohms to preclude the possibility of any significant additional resistance caused by poor electrode-ground contact. However, this is not normally the time of year when high contact resistance would be expected. High contact resistance usually occurs when ground temperatures are low enough to eliminate any free water at the electrode surface. The freezeback value of 360 ohms for electrode 3 shows that the actual increase in effective electrode radius was about 50 cm.

By mid-April, ground temperatures beneath the active layer are usually about 2.0 to 3.0 degrees (Celsius) lower than in September. The resistance to ground value of 1500 ohms (Fig. 6) indicates that the ground resistivity was about 75,000 ohm-cm. This implies that the ground temperature was not significantly different than it was the previous September and may indicate some spring warming.

CONCLUSIONS

This study shows that the resistance to ground of a simple vertical electrode in perennially frozen silt can be lowered significantly by placing it in a hole having a diameter larger than the electrode and by backfilling the hole with soil whose conductivity has been increased by the addition of salt. This procedure increases the effective diameter of the electrode. Shaped charges provide an excellent means of rapidly producing this hole. This study and those previously conducted by Mellor and Sellmann (1970) and by Benert (1957, 1963) suggest that a standard 6.8-kg (15-lb) military charge can produce an adequate hole in most types of frozen soil. Also, the depth of the hole produced by a charge of this size is greater than that of most seasonal frost layers, so that the more conductive thawed material below becomes accessible. An additional benefit of this technique may be that rods installed in salted holes could be recovered for reuse.

RECOMMENDATIONS

To completely evaluate the potential of this technique, additional observations need to be conducted in a range of materials with varying degrees of permeability, including coarse-grained sediments. Seasonal observations should be made at sites in both northern and interior Alaska. These additional measurements would help to determine the influence of ground temperature and associated variations of unfrozen water content on performance of grounding installations.

Ground rod configurations using multiple electrodes can give lower resistance to ground values. For example, four parallel connected electrodes installed in the same manner as electrode 3 would further reduce the resistance to ground from 360 to about 100 ohms (Tagg 1964).

In soils having high ionic diffusion rates, the addition of conductive material (salt) to a crater may result in a gradual lowering of ground resistance over an extended period of time (years). This may not be significant in frozen silt where ionic diffusion rates of 2.5 cm/year have been estimated (Murrmann 1973). However, future observations at this site will help to determine the long-term influence of salt backfill.

A practical problem associated with a winter installation of this type would be that the shaped charge will likely produce an open hole with potential backfill widely scattered. It may not be possible to gather enough backfill, thereby requiring use of something other than mineral soil for this purpose. Snow could be melted for water, and some absorbent material (toilet paper, for example) along with salt and water would likely have to be compacted into the hole around the electrode. The performance of such an installation in gravelly material in unknown, and would depend on the permeability and grain size of the material.

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