IMPULSE RADAR FAMILIARIZATION

AND

TESTING ON RADAR SITES IN FAIRBANKS AREA

FINAL REPORT

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Foreword

The following is a brief report on the measurements of thaw fronts in roadbeds and other near-surface structures using a GSSI subsurface interface radar system. As indicated in the report, the instrument is potentially useful for a variety of other soil investigation applications. Its employment should be considered in situations requiring high subsurface feature resolution and in soil conditions where a reasonable chance for extracting useful information exists.

However, because it is operationally difficult to use and because the records are not easy to interpret, it does not appear, at present, to be suitable for general day-to-day departmental use in its present form. This situation will change with time as more and more private and governmental research effort is expended on the utilization of this technique.

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Funds were granted by the Alaska Department of Transportation and Public
Facilities (DOTPF) to the Geophysical Institute to familiarize Institute
personnel on the use and application to embankment problems of an impulse
radar manufactured by Geophysical Survey Systems, Inc. (GSSI). This
subsurface interface radar system (SIR system) has proven to be useful
elsewhere in some applications involving permafrost/ice studies, mineral
exploration and construction.

Remote-sensing instruments which can detect the presence of ice and
permafrost and the location of the thaw front at spring breakup would be
extremely useful relative to road construction and maintenance. In
particular, it was thought that the position of the thaw front in road
embankments at spring breakup might be detectable by the radar unit. The thaw
front position is directly correlatable to road damage in spring and hence to
load restriction requirements.

The radar unit was tested at four different sites in the Fairbanks area
to familiarize Institute personnel on the operation of the system and
interpretation of records. These sites were chosen because some ground
"truth" is available at all these sites, although exact depths to the thaw-
freeze front was unknown for two of the sites at the time of measurements.
These sites were (1) Farmers Loop sinkhole (Sweet and Connor, 1980), (2)
Engineer Creek Roadcut (Osterkamp and Jurick, 1980), (3) Alder Creek
embankment, and (4) three different locations on farmland of the Agriculture Experiment Station (AES) including the artificial ice mass. Site (1) was chosen for the thaw-freeze front study, because of proximity to the University and because the embankment temperature profile is closely monitored throughout the year. Sites (4) were chosen for reference and familiarization with the equipment. We first discuss the data obtained from the sites (4).

AES Farmland Sites

Several traverses were made in the area of the gray shack near the old Chena Pump Road across farmland at the AES, Fairbanks. These show there exists little or no shallow subsurface geologic features. The area is underlain by a few tens of feet of silt with the water table at about 12 feet and permafrost at about 27 feet. The thaw at the time of the radar measurement (early May, 81) was just over a foot below the surface. The proximity of the thaw front to the surface did not allow separation of the echoes from the thaw front and air-ground interface. Strong echoes were observed at a depth between 10 to 15 feet suggesting the signal had penetrated to the water table.

The second radar traverse on the farm fields was made at the southeast corner of the cultivated area near the meteorological shack adjacent to an area of virgin spruce trees and scrub willow, to determine the capability of the radar to detect the permafrost table which varies from about 5 feet in the spruce to 15 feet under the willow to 25-30 feet under the cultivated fields. At that time (early May, 81) only a traverse through the willows into cultivated fields was made due to difficulties in pulling the antenna through the spruce trees. There appeared to be dipping of a layer at the expected
location and depth of the permafrost layer as one passed out of the area of willows, but the weak signals preclude definitive conclusions.

The third set of radar echo-soundings on AES farmland was made at the site of the artificial ice mass constructed under a DOTPF grant during winter, 1980-1981. Figure 1 shows a traverse made perpendicular to the longitudinal axis of the ice mass which has the approximate dimensions 40 m x 0.6 m x 3.2 m (131' x 2' x 10.5', L x W x H) buried with top face at a depth of 1.2 m (4'). Interpretation of this record near the surface is relatively straight-forward due to the known geometry and location of the ice mass.

The backfill over the ice mass is clearly defined as indicated by the arrows which delineate the edges of the ice mass. In the woods some 7-8 m (22-25') from the edge of the ice mass the depth to thaw measured by probing was approximately 0.7 m (1.25') (including a 3-4" moist vegetative mat) in September, 1981 when the traverse was made. We identify the set of dark bands at 17 x 10⁻⁹ s (17 ns) from the surface at the extreme right of Figure 1 as the base of the active layer in the woods. Assuming the dielectric constant εᵣ = 10 (water saturated silt), the depth of thaw in the woods can be calculated from d = ct/2√εᵣ, where c = 3 x 10⁸ m/s and t = 17 ns. This gives d = 0.81 m, a value fairly close to the measured value of 0.7 m.

The darkest triple bands which extend across the record represent a single interface between two materials of differing dielectric constant. (The three-banded system is inherent to the GSSI radar being caused by oscillations of the reflected radar pulse and limits the resolution of the system to layers separated by at least 2 feet, because of signal superposition). It is tempting to assume that the bands represent the thaw front, which, because of the exposure of ice mass area to direct sunlight and to precipitation, deepens
over the ice mass. If the thaw front is taken to be at a depth in time of
33 ns over the ice mass as indicated in Figure 1, the depth with \( \varepsilon_r = 10 \) is
1.57 m (5.14'). The actual value as determined by probing was about 1.22 m
(4.0'). This discrepancy may be accounted for by assuming a greater value for
\( \varepsilon_r \) which may be reasonable because the backfill silt appeared to contain
considerably more water than normal, undisturbed, water-saturated silt.

There is a definite three-banded structure at 50 ns from the surface
within the ice mass. Assuming \( \varepsilon_r = 4 \) for fresh water ice and that the
interface at 33 ns is the top of the ice mass, the depth below the top of the
ice corresponding to the 50 ns time is 1.28 m, which does not correspond to
any known physical interface. It may arise from multiple reflections with the
trench walls and transmissions through the corners of the ice mass and the
corners of the backfill at the ice-backfill interface.

If the interface at 33 ns is taken as the surface of the ice mass, then
with \( \varepsilon_r = 4 \) for fresh water ice, the travel time to the base of the ice and
return is 43 ns. This is indicated by the dotted line located between 73 and
83 ns from the surface. It is clear that signal is returning from this depth,
but that there is considerable superposition and the three-banded structure
characteristic of an interface is lost such that one cannot readily identify
the location of the base of the ice mass.

**Engineer Creek and Alder Creek**

Figure 2 shows the record of a single traverse made in the Engineer Creek
roadcut which has been previously studied by other means (Osterkamp and
Jurick, 1980). A conduit approximately 6 feet below the road surface was
readily identifiable, but only because its location was known (459 + 15)
beforhand. On the other hand, a subcut-to-bedrock interface at a depth of 15 feet between 461+00 and 463+00 is not identifiable in the traverse.

It appears from this traverse that most of the energy transmitted by the radar antenna has absorbed within the first few feet of the surface of the roadbed. In part this may be due to the relatively high conductivity of the strata below the roadbed which is known to be Birch Creek Schist, a common bedrock underlying much of the Fairbanks area. Its conductivity is of order 5-10 mmhos/m. In contrast, the frozen silt on the AES farmland has a conductivity of order 2.4 mmhos/m. Attenuation of electromagnetic energy varies directly with conductivity.

Although conductivity is an important factor in signal attenuation, a possibly greater factor in signal loss with regard to the Engineer Creek traverse may be the presence of multiple interfaces which in effect trap much of the incident energy in multiple reflections. Typically in a roadbed, there are as many as 6 interfaces within 5 to 10 feet of the surface, if the air-asphalt interface is counted. Also the information that might be gained from the data of a multi-layered structure is limited because the radar echoes are sampled in the time domain and superposition of signals can occur if the layers are closely spaced.

The radar unit was also operated over a 2500 ft length across the fill embankment over Alder Creek. The data from this site was similar to that of the Engineer Creek Roadcut site in that little penetration was noted. In addition, the equipment was operating only marginally at this time.

Farmers Loop Sinkhole

In an attempt to follow the thaw front down at spring breakup three traverses spaced over a six day period (May 6, 8 and 11, 1981) were made along
a section approximately 250 feet in length in the inner north-bound lane off Farmers Loop Road spanning the area of the sinkhole from about station 7+18 to 9+68. An earlier traverse was made with a 300 Mhz antenna borrowed from CRREL personnel on May 1, 1981 across the same area, but directly over the centerline so that the records from the two antennas could not be readily compared.

Figures 3, 4 and 5 show passes made on May 6, 8 and 11, respectively. For reference, the locations of boreholes at stations 7+60 and 8+05 measured along Farmers Loop Road from the College Road intersection are indicated (see Sweet and Connor, 1980 for detailed borehole information). Two separate passes for two different penetration depth settings are shown on the right hand sides of Figures 3 and 4. The records are exceedingly complex due to the structure of the embankment which has at least 4 interfaces between materials of differing dielectric constant at station 7+20 and 5 interfaces at station 7+80 (see Sweet and Connor, 1980) within 15' of the road surface. The ribbed structure at depth which decreases as one goes to the right is the signal from overhead wires.

Laterally it is evident that the first layer is relatively homogeneous, but as one proceeds north from 7+60 the strata begins to dip (see arrow in Figure 4). This corresponds to the beginning position of the sinkhole, where for several years layer upon layer of asphalt have been laid as the pavement surface sank. It is clear the bottom surface of the built up asphalt layer is irregular from the irregular nature of the radar returns. According to Sweet and Connor (1980), the asphalt layer reaches a maximum depth of about 5' between stations 8+05 and 8+30. The irregular feature closest to the top beginning at about station 7+80 (see arrow in Figure 5) appears to be an artifact due to multiply reflected signals; however, the possibility that the
asphalt at depth (~1-3 feet) may be folded and contain distinct pockets of gravel or other material cannot be ruled out.

A quick comparison of the three traverses made over the six day interval indicates there were some definite changes in the underlying strata. Except for the prominent feature which is enclosed by the box in each of the three figures, the changes cannot be followed systematically. The feature in the box remained relatively stable in shape from May 6 to May 8, but clearly it changed form by May 11, 1981. The estimated depth to this feature which appears to be in a layer of fill material consisting of tailings varied from about 3.5' to 4.5'. Temperature measurements taken from a thermistor string located about 200' further up the road by DOTPF/personnel show that the front was about 3' on May 1 and between 4' to 5' on May 11. Thus, the feature enclosed in the boxes may be identified with the thaw front, although we have no independent confirmation of this. The relatively strong echo produced by this feature and its changes with time suggest it is a wet surface or water logged layer, which overlies the still frozen layer below.

Conclusions and Recommendations

An impulse radar such as the GSSI system is complex and requires extensive training and experience both from an operating standpoint and standpoint of data interpretation. The instrument holds great promise for aiding in the solution of many practical problems in regards to near surface geology, although in the present study the results obtained were somewhat inconclusive.

The Geophysical Institute GSSI system includes digital enhancement capabilities at depth and also a second antenna that can be used to determine
the dielectric constant of subsurface materials. We have yet to practice with these options.

The instrument in its present form (100 Mhz antenna) appears to be capable of detecting and mapping ground ice embedded in permafrost soils and also in determining depth to bedrock through soils and gravels up to a few tens of meters in thickness. It is therefore recommended that a grid survey be made with the GSSI radar at some selected site where there exists a shallow layer of soil containing ground ice overlying bedrock. It should be used in conjunction with an induction probing device such as the EM-31 which will give a quick overview of the area.

The 100 Mhz antenna used with our GSSI system is not very practical in determining depth to thaw front in embankments. It is thus recommended that vendors of impulse radars be contacted to determine whether existing radar systems may be modified using higher frequency antennas, perhaps in the dual antenna configuration to pinpoint the thaw front in a multi-layered medium such as a roadbed.
References


FIG. 1
Farmers Loop Sinkhole

5 / 6 / 81

Fig. 3
Farmers Loop Sinkhole

5 / 8 / 81

Fig. 4
Farmers Loop Sinkhole

5 / 11 / 81

Fig. 5