Rowan University
CENTER FOR RESEARCH & EDUCATION IN ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

Technical Brief

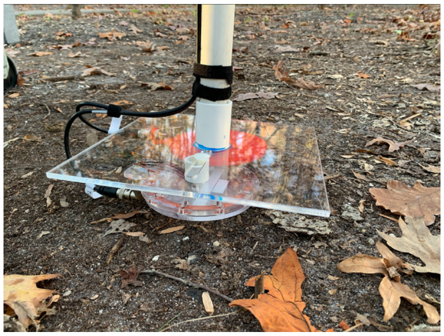
Noninvasive Characterization of Frozen Soils Using iFROST MAPPER

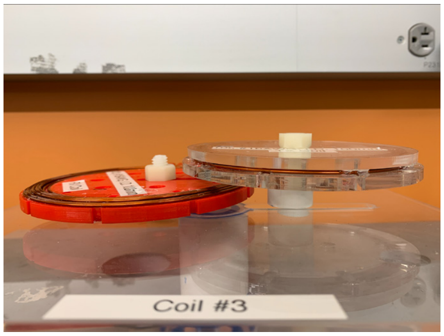
Background

The engineering issues of cold region's infrastructure related frozen soils in recent years have raised concerns from the United States Department of Defense. High-frequency Electromagnetic induction (HFEMI) has been utilized in the past by the United States Army Corps of Engineers as a method of detecting unexploded ordinance. Alternatively, method of HFEMI, when being integrated with electrical resistivity imaging, is a promising technique to provide a rapid and cost-effective solution to ground surveying in cold regions.

Research Objectives

The main objective of this research is to investigate the spatiotemporal evolution of frozen soils under changing temperature conditions with electrical resistivity measurement and electro-magnetic induction methods. We aim to establish the relationship between electrical and geotechnical properties by laboratory and field tests with electrical resistivity measurement and EMI method. The coupled model will be calibrated with laboratory test and implemented into finite element analysis. The influencing factors considered in this study mainly include initial water content, bulk density, and temperature.





Direct Benefit to Military Engineering

This project will lead to the development of a novel truck-mounted permafrost assessment and mapping system consisting of measurement devices and methods for rapid and noninvasive permafrost soil characterization in cold regions. The integrated system will be capable of acquiring and analyzing impedance survey data, deduce soil physical and mechanical properties, and map associated 3D geographical and geotechnical profiles. The advances achieved with the developed integrated system will enable longstanding field-scale characterizations, shorten the time needed for site investigation and thereby speed construction of vital infrastructure in cold regions.

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Conclusions and Recommendations

In this study, under freeze-thaw conditions, we carried out lab-scale 1D electrical resistivity measurements on frost-susceptible soils with varying water content and bulk density properties. We use a portable electrical resistivity meter for temporal electrical resistivity measurements and thermocouples for temperature monitoring. We have implemented empirical model from our experiments into a COMSOL finite element model at both laboratory and field scales which enables the simulation of soil electrical resistivity response under both short-term and long-term sub-freezing conditions. The main conclusions are listed as below:

- Below 0°C, soil resistivity increases with the decreasing temperature. There also exists an electrical resistivity hysteresis phenomenon for the soils tested under freeze–thaw temperature variations.
- A sigmoidal model has been developed to fit experimental data and capture the hysteresis phenomenon. The model uses soil temperature and moisture content-dependent material properties as inputs.
- Changes of atmospheric temperature in short-term and long-term periods lead to soil temperature change, and thereby phase transition in the pore fluid between ice and water, and electrical resistivity change.
- The relationship between soil electrical resistivity and soil geotechnical properties including initial water content and NaCl concentration under freeze-thaw conditions is established. From testing results, a statistical model is built to show relationship between electrical resistivity and temperature during freezing and thawing.

Related Publications

Kang, J., & Schmalzel, J. (2021, August). Extension of the IEEE 1451 Standards to Geophysical Assessment. In 2021 IEEE Sensors Applications Symposium (SAS) (pp. 1-6). IEEE.

Liu, R., Offenbacker, D., Zhu, C., Schmalzel, J., Mehta, Y., Barrowes, B., ... & Lein, W. (2021). Freeze-Thaw Electrical Resistivity Hysteresis Response of Frost Susceptible Clayey Sands. In IFCEE 2021 (pp. 350-359).

Liu, R., Zhu, C., Schmalzel, J., Offenbacker, D., Mehta, Y., Barrowes, B., ... & Lein, W. (2022). Experimental and numerical analyses of soil electrical resistivity under subfreezing conditions. Journal of Applied Geophysics, 202, 104671.

Thurston, G. D., Schmalzel, J. L., & Barrowes, B. (2021, August). Next Generation Geophysical Assessment System. In 2021 IEEE Sensors Applications Symposium (SAS) (pp. 1-6). IEEE.

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More details about the study will be available at rowan.edu/creates

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