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# RPPR Final Report

as of 21-Oct-2021

Agency Code: 21XD

Proposal Number: 74834EGRI

Agreement Number: W911NF-19-1-0134

## INVESTIGATOR(S):

**Name:** Lee Slater  
**Email:** lslater@newark.rutgers.edu  
**Phone Number:** 9733535109  
**Principal:** Y

Organization: **Rutgers, The State University**

Address: 249 University Avenue, Newark, NJ 071021808

Country: USA

DUNS Number: 130029205

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**Report Date:** 31-Dec-2020

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**Final Report** for Period Beginning 27-Feb-2019 and Ending 30-Sep-2020

**Title:** Acquisition of mechanical testing instrumentation in support of research on the electrical geophysical properties of soils

**Begin Performance Period:** 27-Feb-2019

**End Performance Period:** 30-Sep-2020

**Report Term:** 0-Other

Submitted By: Lee Slater

Email: lslater@newark.rutgers.edu

Phone: (973) 353-5109

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

**STEM Degrees:** 1

**STEM Participants:** 1

**Major Goals:** The major goal of this project was to acquire key instrumentation to enhance basic earth materials and processes research on the relationships between the electrical and mechanical properties of sediments being performed under ARO Research and Education Program (REP) project W911NF-18-1-0442. The acquired instrumentation was selected to significantly expanded the capabilities of the Near Surface Geophysics (NSG) research laboratory at Rutgers University Newark (RUN) to include soil strength/failure testing according to ASTM standards. The instrumentation (that could not be included in the REP proposal due to budgetary limitations) would dramatically enhance the quality of the ARO-funded research performed at RUN by allowing direct measurements of soil strength/failure parameters for correlation against electrical geophysical signals. The goal of the research conducted with these instruments was to generate new information on the sensitivity of advanced, broadband, low frequency complex electrical measurements to soil compression and failure. The basic research conducted with this instrumentation will ultimately contribute to efforts at remote assessment of soil geotechnical properties. The specific aim of the instrumentation purchase was to permit high quality, automated measurements of strain and strength/failure parameters on a wide range of unconsolidated sediments of relevance to ARO. The goal was to acquire instrumentation that is expandable, allowing the in-situ measurements of complex electrical properties during uni-axial and triaxial strength testing.

**Accomplishments:** Activities on this award included background research on procuring a triaxial system offering compatibility with a complex electrical conductivity measurement device. This resulted in the purchase of a complete triaxial system from instrumentation provided by two vendors: Humboldt Manufacturing and Wykeham Farrance (part of Controls Groups). Specific details of the purchased equipment are provided in the supporting PDF. Without this instrumentation, the scope of the research under W911NF-18-1-0442 would have been limited to relatively simple experiments on soil electrical properties as a function of variations in soil compaction and particle packing. The acquired instruments are capable of conducting a broad range of American Society for Testing and Materials (ASTM) standard tests, and also have the capabilities for interfacing with complex conductivity instrumentation owned by RUN. The complex electrical measurements required the design and construction of a compressible/expandable soil sample holder with zero resistance against uniaxial/triaxial load. The sample holder, designed by RUN personnel working on W911NF-18-1-0442, was equipped with ports for mounting electrodes needed for complex conductivity measurements and functioned effectively. Cable-access ports on the purchased triaxial cell can withstand up to 3500 kPa pressure during a full triaxial test without leaking. The volume controller of the purchased triaxial system supports non-ASTM standard tests needed to fully explore the complex electrical properties of soils during compression and failure tests. The fully optimized setup is remotely operable (i.e. off campus) via an active internet connection. Photos illustrating the instrumentation purchased and the setup at

# RPPR Final Report

## as of 21-Oct-2021

Rutgers University Newark are included in the supporting PDF document.

The completed setup is capable of all ASTM standard tests for quantifying soil strength/failure parameters as well as concurrent measurements of the complex conductivity signatures of soil samples. Furthermore, it is possible to design user-defined tests that do not follow the ASTM standards. Without this setup, it was impossible to gain full control over all failure parameters (e.g., shear point, maximum load, yield, drainage volume, etc.) as well as complex properties of the soil (e.g., surface conductivity) in real time. All the measurements can be synced to start at the same time and collect data at the same rate. The data collection rate can be as small as 0.01  $\mu\text{m}/\text{minute}$ , including measurement of saturation volume change (precision: 1  $\mu\text{L}$ ), pore and cell (confining) pressure (precision: 1 mPa), applied load (precision: 0.01 N), strain (precision: 1  $\mu\text{m}$ ) as well as complex conductivity phase shift (from 1 mHz to 20 kHz) and magnitude. These high accuracy sensors allow for precise assessment of complex properties of soils under different failure scenarios (e.g., different vertical loads). The supporting PDF document shows example datasets acquired with the new instrumentation that illustrate its value and the promising results coming from the basic research that the instrumentation supports.

**Training Opportunities:** The acquired instrumentation provided unique opportunities for the postdoctoral student (Saneiyan) working under W911NF-18-1-0442 to acquire new skill sets and familiarity with triaxial testing instrumentation. He received guidance and training on the instrumentation from the equipment manufacturer. During the spring 2020 semester, one undergraduate student received training from Saneiyan on the basics of triaxial testing and complex electrical conductivity measurements. This student was supervised by the PI and Saneiyan on 6 credit hours of undergraduate laboratory research credit. During summer 2020 session, Slater and Saneiyan supervised two underrepresented minority (URM) students in an online research experience funded by a National Science Foundation (NSF) award to promote diversity in STEM. The students worked on modeling the complex electrical measurements being acquired with this instrumentation.

**Results Dissemination:** The availability of the new instrumentation and its capabilities was described to Dan R. Glaser, PG, PMP, Research Geophysicist, Signature Physics Branch, Cold Regions Research & Engineering Laboratory (CRREL), Engineer Research & Development Center of the US Army Corps of Engineers, who served as a project partner to ensure that the basic research conducted with the purchased instrumentation is relevant to the ARO mission. Postdoctoral scientist Saneiyan has also given webinars on his work with the instrumentation as part of a Hydrogeophysics Knowledge Exchange webinar series convened by students at Rutgers University Newark and Lancaster University (UK). Saneiyan also led a poster presentation on the work at the Fall 2020 American Geophysical Union (AGU) meeting. A paper on the first experiments performed with the instrumentation was submitted to the journal Engineering Geology in January 2021.

**Honors and Awards:** Nothing to Report

**Protocol Activity Status:**

**Technology Transfer:** Nothing to Report

### PARTICIPANTS:

**Participant Type:** Postdoctoral (scholar, fellow or other postdoctoral position)

**Participant:** Sina Saneiyan

**Person Months Worked:** 2.00

Project Contribution:

National Academy Member: N

**Funding Support:**

**Participant Type:** Undergraduate Student

**Participant:** Ethan Siegenthaler

**Person Months Worked:** 1.00

Project Contribution:

National Academy Member: N

**Funding Support:**

**RPPR Final Report**  
as of 21-Oct-2021

**Partners**

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I certify that the information in the report is complete and accurate:

Signature:

Signature Date:

74834-EV-RI, Agreement Number: W911NF-19-1-0134

Acquisition of mechanical testing instrumentation in support of research on the electrical geophysical properties of soils

## **FINAL REPORT – TECHNICAL SECTION**

### **SCIENTIFIC PROGRESS AND ACCOMPLISHMENTS**

#### **Objectives**

The objective of this project was to acquire key instrumentation to enhance basic earth materials and processes research on the relationships between the electrical and mechanical properties of sediments being performed under ARO Research and Education Program (REP) project W911NF-18-1-0442. The acquired instrumentation significantly expanded the capabilities of the Near Surface Geophysics (NSG) research laboratory at Rutgers University Newark (RUN) to include soil strength/failure testing according to ASTM standards. The instrumentation (that could not be included in the REP proposal due to budgetary limitations) dramatically enhanced the quality of the ARO-funded research performed at RUN by allowing direct measurements of soil strength/failure parameters for correlation against electrical geophysical signals. The research conducted with these instruments has generated new information on the sensitivity of advanced, broadband, low frequency complex electrical measurements to soil compression and failure. The basic research conducted with this instrumentation will ultimately contribute to efforts at remote assessment of soil geotechnical properties. The acquired instrumentation permits high quality, automated measurements of strain and strength/failure parameters on a wide range of unconsolidated sediments of relevance to ARO. Critically, the instrumentation purchased was expandable, allowing the in-situ measurements of complex electrical properties during uni-axial and triaxial strength testing.

#### **Outcome**

Activities on this award included background research on procuring a triaxial system offering compatibility with a complex electrical conductivity measurement device. This resulted in the purchase of a complete triaxial system from instrumentation provided by two vendors: Humboldt Manufacturing and Wykeham Farrance (part of Controls Groups). Specific details of the purchased equipment are provided in Table 1. Without this instrumentation, the scope of the research under W911NF-18-1-0442 would have been limited to relatively simple experiments on soil electrical properties as a function of variations in soil compaction and particle packing. The acquired instruments are capable of conducting a broad range of American Society for Testing and Materials (ASTM) standard tests, and also have the capabilities for interfacing with complex conductivity instrumentation owned by RUN. The complex electrical measurements required the design and construction of a compressible/expandable soil sample holder with zero resistance against uniaxial/triaxial load. The sample holder, designed by RUN

personnel working on W911NF-18-1-0442, was equipped with ports for mounting electrodes needed for complex conductivity measurements (Figure 1) and functioned effectively. Cable-access ports on the purchased triaxial cell can withstand up to 3500 kPa pressure during a full triaxial test without leaking (Figure 2). The volume controller of the purchased triaxial system supports non-ASTM standard tests needed to fully explore the complex electrical properties of soils during compression and failure tests. Figure 3 shows a complete setup that is fully optimized for experiments underway in REP project W911NF-18-1-0442. This setup is remotely operable (i.e. off campus) via an active internet connection.

Table 1: Detailed list of equipment components purchased to construct a triaxial setup supporting complex electrical measurements during strain/failure tests

<b>Humboldt Manufacturing</b>		
<i>Item</i>	<i>Part number</i>	<i>Quantity</i>
50kN (11240 lbf) capacity load frame	HM-5030.3F	1
Load Cell	HM-2300.020	1
Strain Transducer (LSCT)	HM-2310.20	1
Ball Seat Adapter	HM-200387	1
Strain Transducer Bracket	HM-4178BRT	1
Pressure Distribution Panel (3 cell)	HM-4155	1
Air/Water Bladder	HM-4151A	2
Pressure/Volume Controller	HM-5240.3F	1
De-airing System	HM-4187A.3F	1
Vacuum Pump	H-1763A or H-1763A.4F	1
Air Compressor	HM-4220 or HM.4220.4F	1
Installation Kit	HM-4167	2
Sample preparation kit	various	1
<b>Wykeham Farrance (part of Controls Groups)</b>		
Banded triaxial cell for up to 70mm diameter	WF4070	1
Advanced upgrading kit for triaxial cell mod.	WF4070/ADV	1
Pedestal 38mm	WF4031/7	1
Top cap 38mm	WF4032/A	1
Pedestal 50mm	WF4051/7	1
Top cap 50mm	WF4052/A	1
Bender element, 50 mm top cap, base pedestal	WF4057/PS	1
Bender element - Master signal conditioning control Unit	WF4200	1

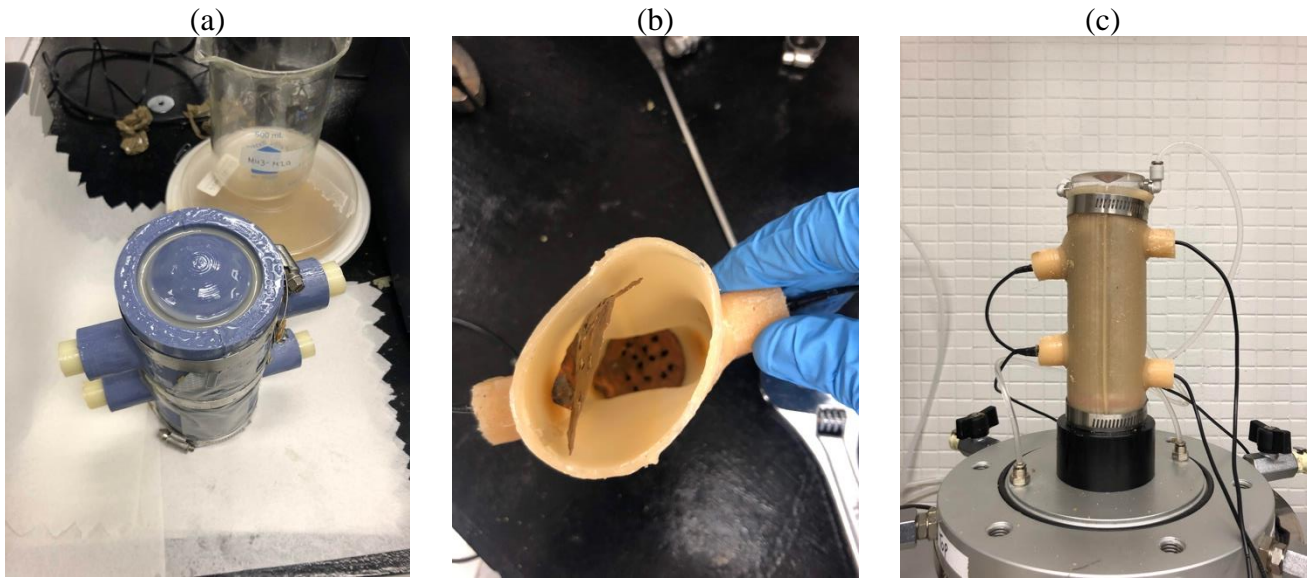


Figure 1: Building the flexible soil sample holder. a) 3D printed mold with liquid rubber compound curing inside, b) final flexible sample holder with mounted electrode inside and c) flexible sample holder filled with unconsolidated soil sample mounted on the triaxial pedestal unit.

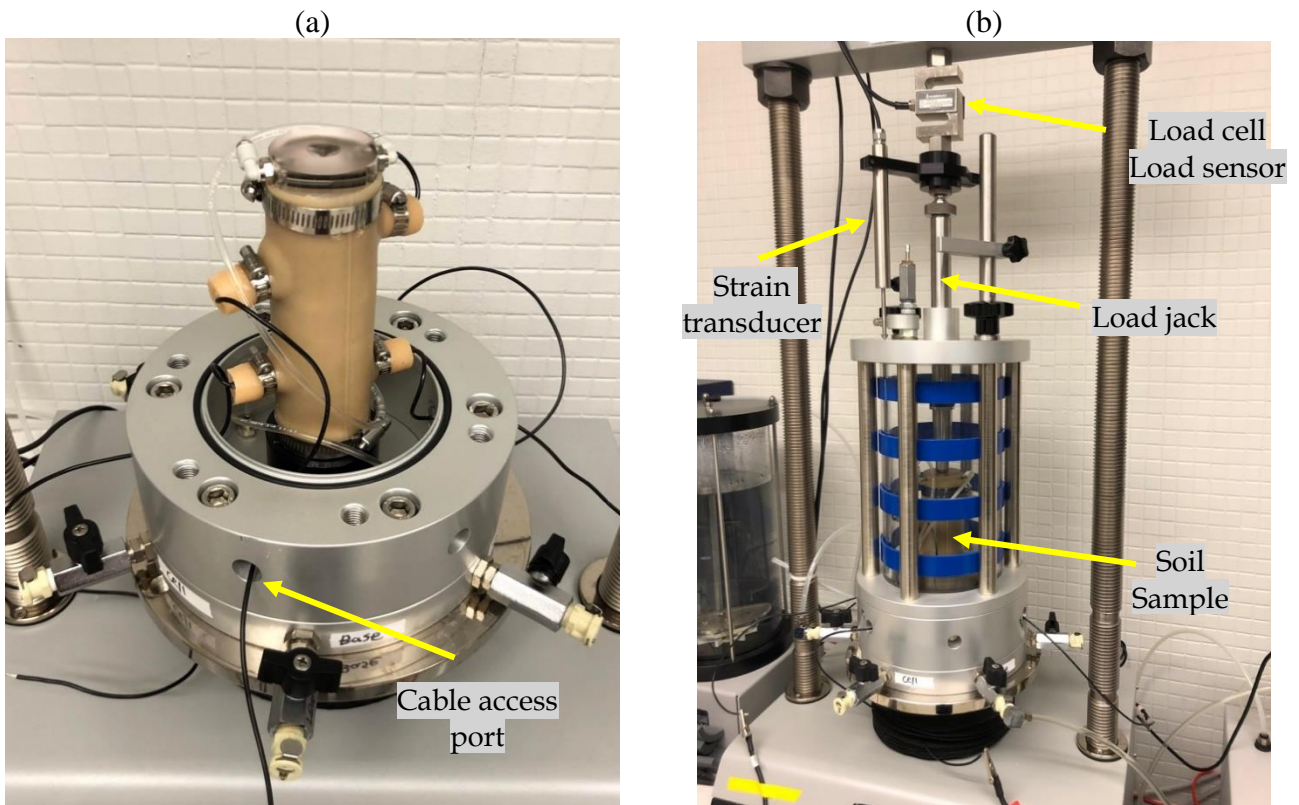


Figure 2: a) extension added to the standard triaxial cell which allows for cable access for complex conductivity electrodes and b) customized triaxial cell with sample inside, loaded on the triaxial load frame ready for concurrent complex conductivity and triaxial shear measurements.

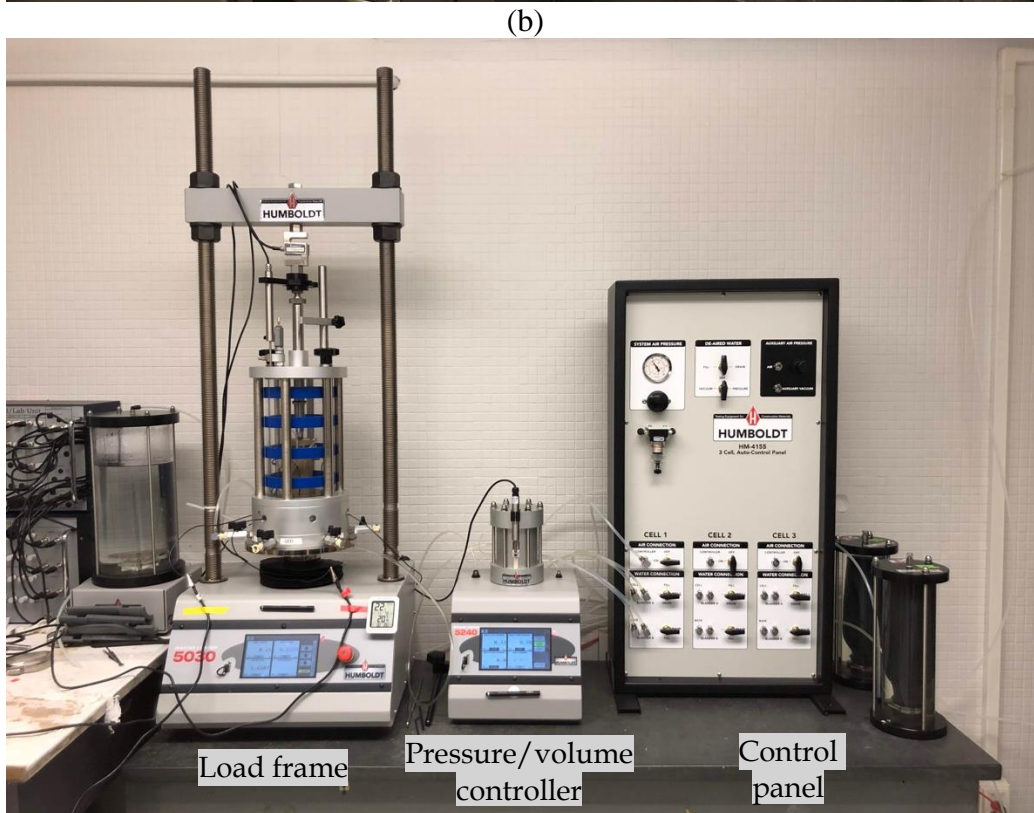
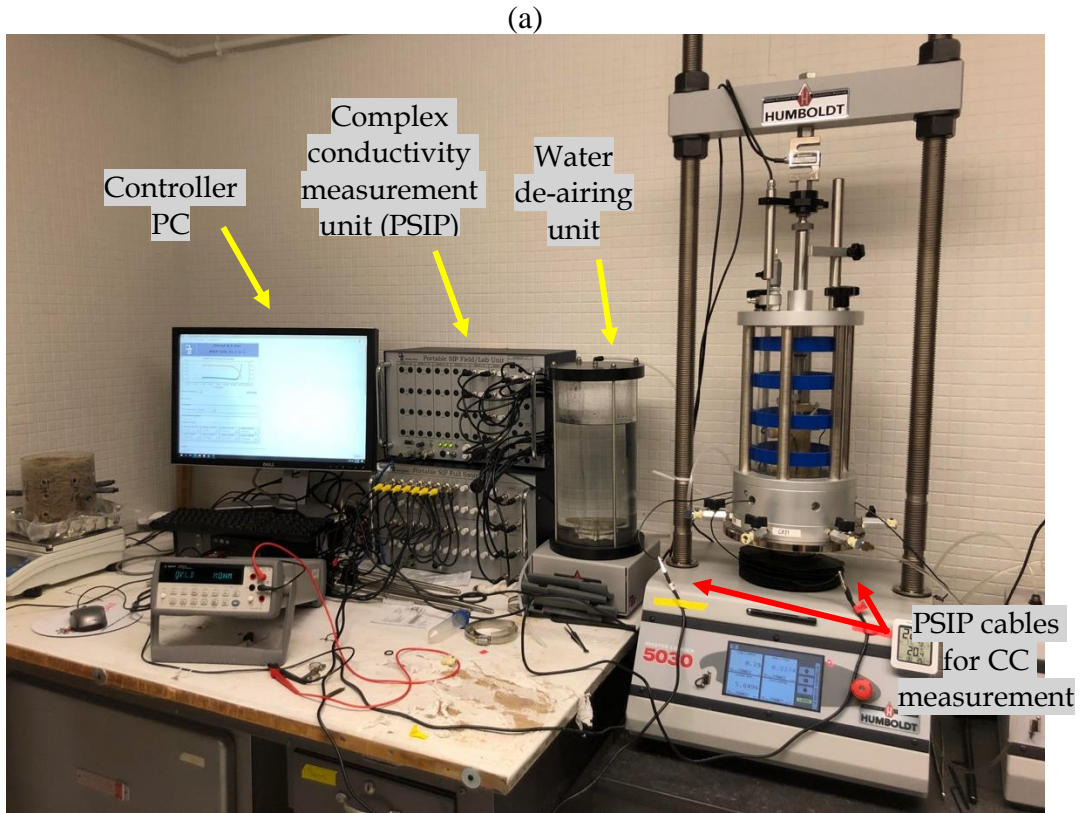
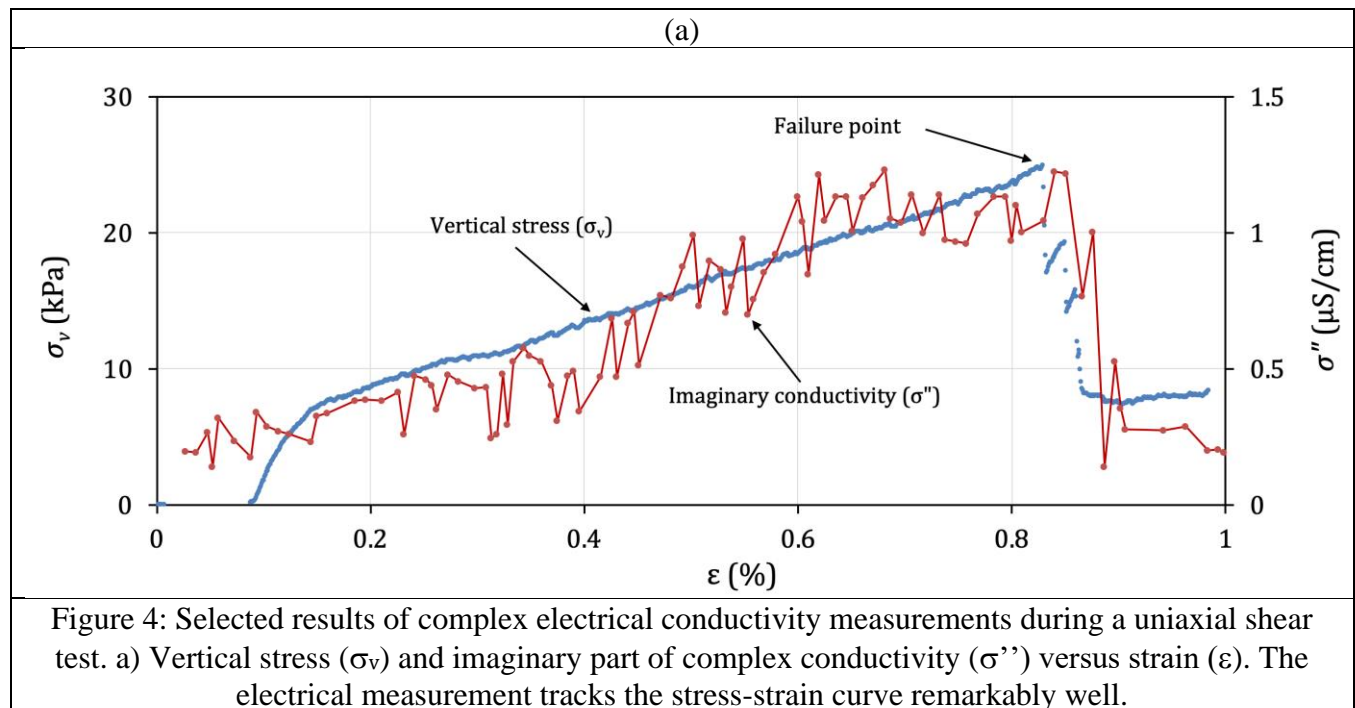


Figure 3: complete triaxial setup with complex conductivity measurement capability. a) computer and complex conductivity controller unit and b) automatic triaxial setup

The completed setup is capable of all ASTM standard tests for quantifying soil strength/failure parameters as well as concurrent measurements of the complex conductivity signatures of soil samples. Furthermore, it is possible to design user-defined tests that do not follow the ASTM standards. Without this setup, it was impossible to gain full control over all failure parameters (e.g., shear point, maximum load, yield, drainage volume, etc.) as well as complex properties of the soil (e.g., surface conductivity) in real time. All the measurements can be synced to start at the same time and collect data at the same rate. The data collection rate can be as small as 0.01  $\mu\text{m}/\text{minute}$ , including measurement of saturation volume change (precision: 1  $\mu\text{L}$ ), pore and cell (confining) pressure (precision: 1 mPa), applied load (precision: 0.01 N), strain (precision: 1  $\mu\text{m}$ ) as well as complex conductivity phase shift (from 1 mHz to 20 kHz) and magnitude. These high accuracy sensors allow for precise assessment of complex properties of soils under different failure scenarios (e.g., different vertical loads).

## Early results

Example datasets are shown to illustrate the value of this new instrumentation and the promising results coming from the basic research that the instrumentation supports. Successful uniaxial (no confining pressure applied on the sample) tests show a strong correlation between complex conductivity versus strain and stress versus strain behavior. Figure 4 indicates that the imaginary part of the complex conductivity signal is a promising soil failure predictor under applied vertical loads. Full triaxial shear tests are currently in progress under W911NF-18-1-0442.



## **Collaborations**

Dan R. Glaser, PG, PMP, Research Geophysicist, Signature Physics Branch, Cold Regions Research & Engineering Laboratory (CRREL), Engineer Research & Development Center of the US Army Corps of Engineers has agreed served as a project partner to ensure that the basic research conducted with the purchased instrumentation is relevant to the ARO mission. He is aware of the equipment purchase and how it is enhancing the quality of research being performed by students under W911NF-18-1-0442. Glaser is also a collaborator on W911NF-18-1-0442 and hosted a Rutgers University Newark summer graduate intern at CRREL in July-August 2019.