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INTRODUCTION

- Increase in power demands = infrastructure crossing remote/rugged terrain
  - Permitting, access and schedule challenges limit geotechnical information
  - Foundations designed with incomplete information
  - **Micropiles continue to provide solutions to these challenges**

- Case Study Examples
  - 🔥 **Koolau-Wailupe 46 kV Circuits:** Structure replacement on steep slopes, Hawaii
  - ❄️ **Lower Churchill Project:** New line constructed in freezing temperatures, Canada

KOOLAU-WAILUPE 46 KV CIRCUITS OAHU, HAWAII

KOOLAU-WAILUPE 46 KV CIRCUITS
Project Overview

- Circuits power the substations serving the Hawaii Kai area of Oahu, HI
- Upgrade required after outages – Wood poles to self-supporting steel poles
- Challenges
  - Rugged, remote terrain & steep slopes
    - Road construction not feasible
  - Unpredictable weather
  - In-service overhead lines

KOOLAU-WAILUPE 46 KV CIRCUITS

Micropile Selection

- Foundation requirements:
  - Compact, lightweight materials & installation equipment
  - Compatible with helicopter construction
  - Accommodate low overhead clearance
  - Accommodate unknown and variable subsurface conditions
- Micropiles fit the requirements and were specified for 13 steel poles

KOOLAU-WAILUPE 46 KV CIRCUITS

Subsurface Challenges

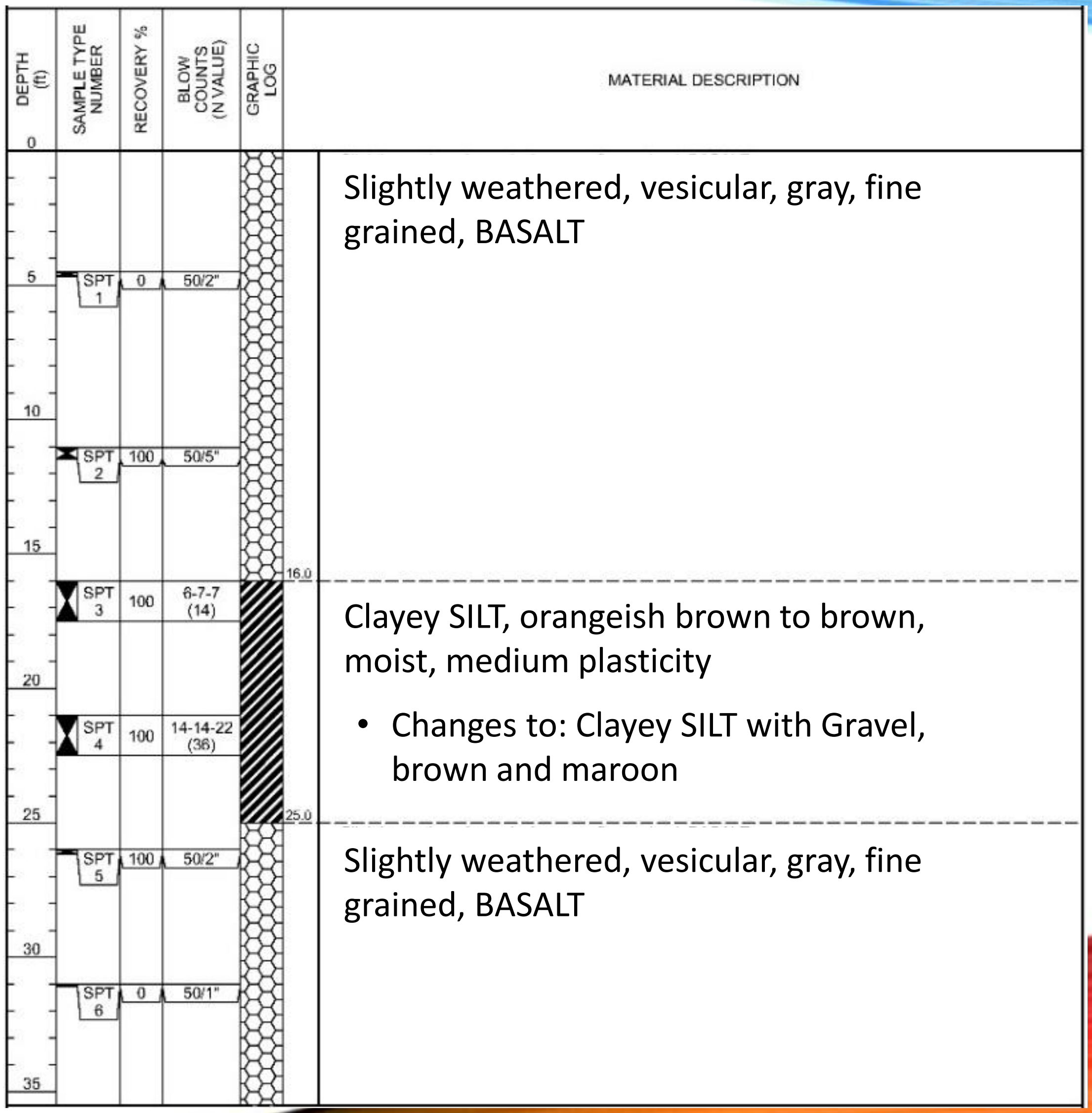
- Initial micropile designs produced from representative data
  - Access challenges did not allow for geotech program prior to construction
  - Common practice in T&D
    - Long, linear nature – number and spacing of structures
    - Permitting and other access restrictions
- Baseline assumptions made from existing data:

Sub Layer		Material Description	Dry Density (kg/m^3)
Top (m)	Bottom (m)		
0	4.5	Saprolite (MH)	880-1280
4.5	9	HW Basalt	1680
9+	-	Saprolite (MH)	1440

KOOLAU-WAILUPE 46 KV CIRCUITS

Subsurface Challenges

- Construction data showed highly weathered basalt and intermittent layers of saprolite (to depths of 18 m)
- Saprolite: Chemically weathered rock found in lower zones of soil profiles → can create MAJOR foundation issues
    - Exhibits strength and stiffness properties of soil
- Precise identification of materials was crucial to foundation performance
- Bond zone composed of materials with varying stiffnesses can lead to pile failure



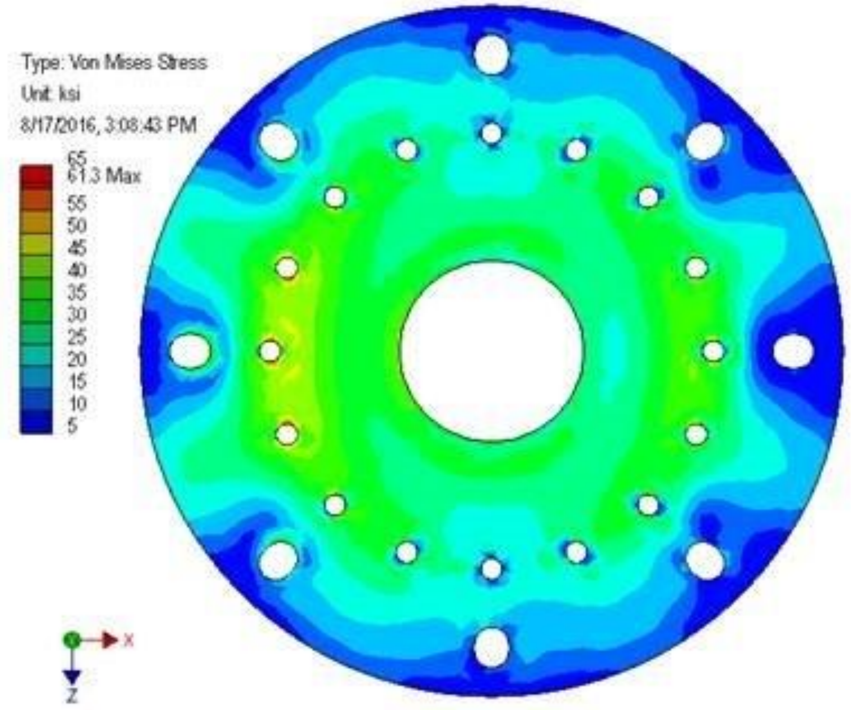
KOOLAU-WAILUPE 46 KV CIRCUITS
Pile Design

- Maximum ground line moment reactions: Approximately 420 to 1240 kN-m
- Detailed foundation schedules created for each site – provided foundation capacities for a range of expected conditions
    - Factored in adjacent slopes, the variable subsurface conditions, and limited data
    - Site topography impacted micropile orientation & layout: Custom lateral resistance models developed
- Varying number of micropiles grouped together with a steel cap
- 3, 6 and 8 pile layouts developed for each site – design selection made during construction

KOOLAU-WAILUPE 46 KV CIRCUITS

Steel Pile Caps

- Selected in place of concrete due to:
    - Unpredictable weather windows dictated construction schedules
    - Access – concrete unfeasible
- Steel cap design:
    - Single steel plate with openings to accommodate required pile alignment tolerances
    - FEA used to predict bidirectional stress and stress concentrations
        - Also validated plate deflection, buckling and yielding and welding requirements – resulted in reduced weight
    - 5.7-9.5 cm thickness, 147-193 cm diameter



Compared to concrete caps, the steel caps reduce helicopter use by an average 74% and onsite labor time by an average 64%.

KOOLAU-WAILUPE 46 KV CIRCUITS
Construction

Equipment

- Specialty, helicopter-portable micropile drills
- Leveling platforms to neutralize slopes and provide a template for the rotating drill

Overhead Lines

- Brief outages to place equipment, but all drilling under in-service lines
- Combined height of platform and drill had to be less than 4.5 m

Weather Challenges

- Strong winds, rain storms and heavy fog had major impacts on schedule

KOOLAU-WAILUPE 46 KV CIRCUITS

Trouble!

Weather moving in…

KOOLAU-WAILUPE 46 KV CIRCUITS

Helicopter Stand-Down Due to Weather

KOOLAU-WAILUPE 46 KV CIRCUITS

Unwanted Visitors

KOOLAU-WAILUPE 46 KV CIRCUITS
Testing & Quality Control

- Field engineers and geologists onsite
  - Assisted in precise identification of materials
- Proof testing performed on one pile per structure
  - Loads ranged from 965-1635 kN, and corresponding total displacements ranged from 0.58-1.65 cm

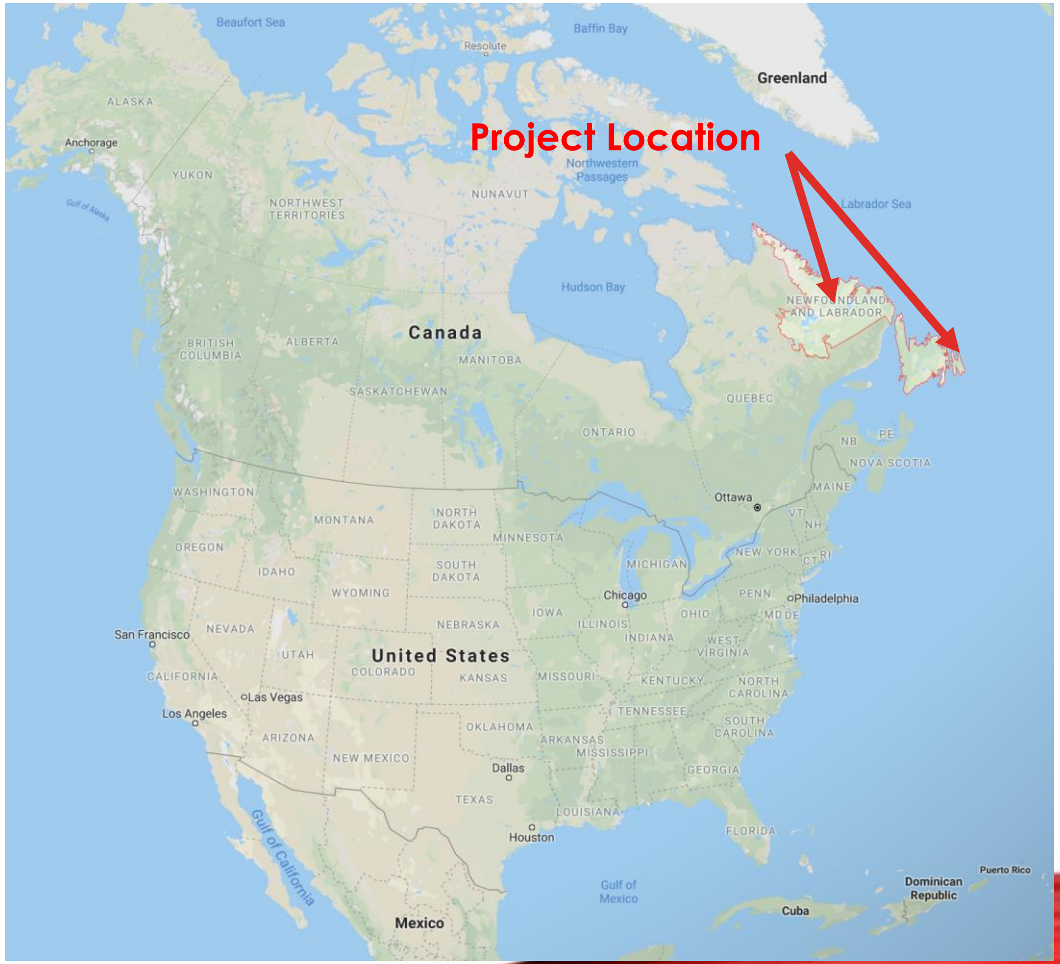
KOOLAU-WAILUPE 46 KV CIRCUITS
Completion

LOWER CHURCHILL PROJECT PROJECT OVERVIEW

LOWER CHURCHILL PROJECT

Project Overview

- Generation and transmission of hydro-power in Newfoundland & Labrador
- Phase I, "Muskrat Falls":
  - Over 1,100 km
  - Approximately 1,260 self-supporting and guyed structures
- Challenges:
  - Boggy conditions – construction took place in winter months
  - Temperatures ranged from -13°C to -40°C
  - Average annual snowfalls of 458 cm occurring over 10 months of the year



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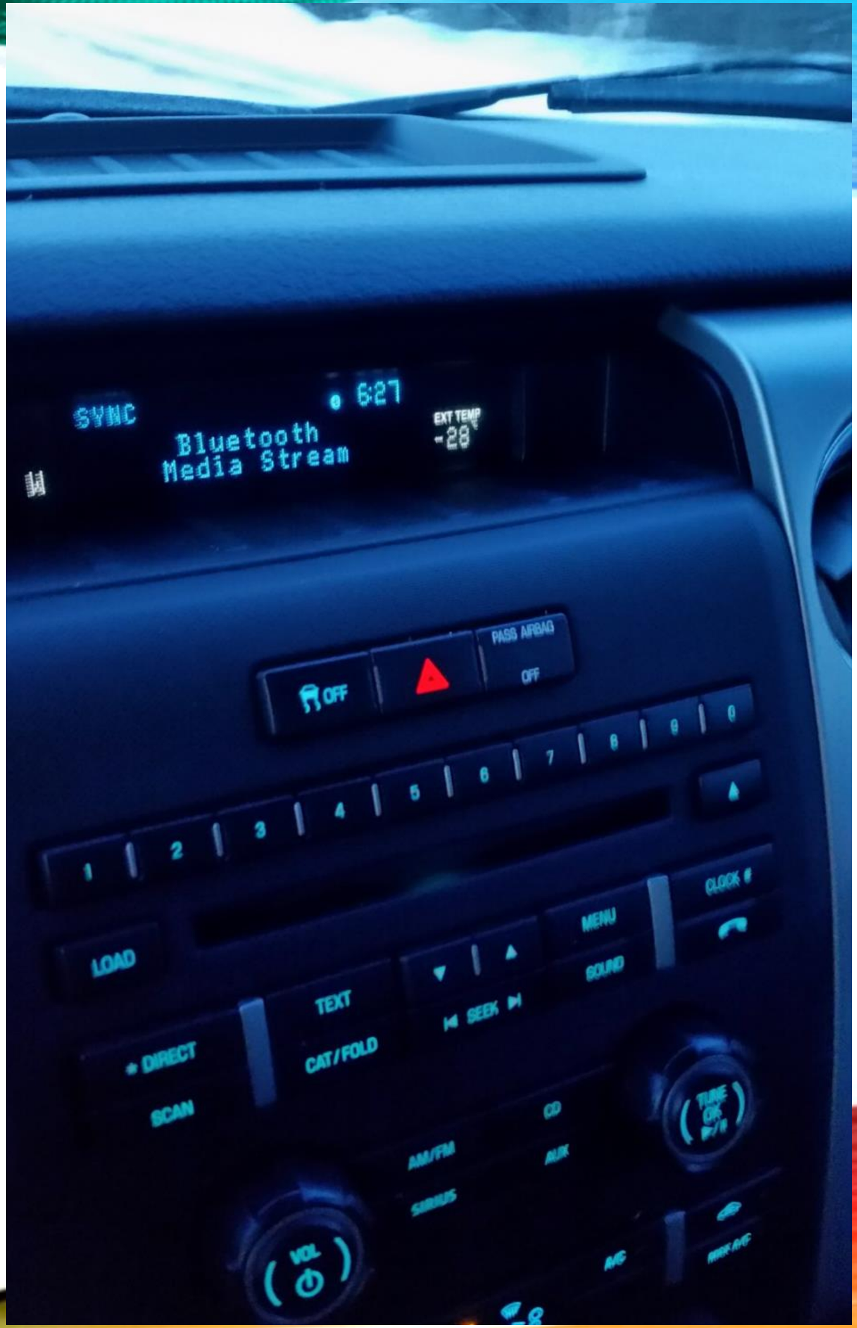

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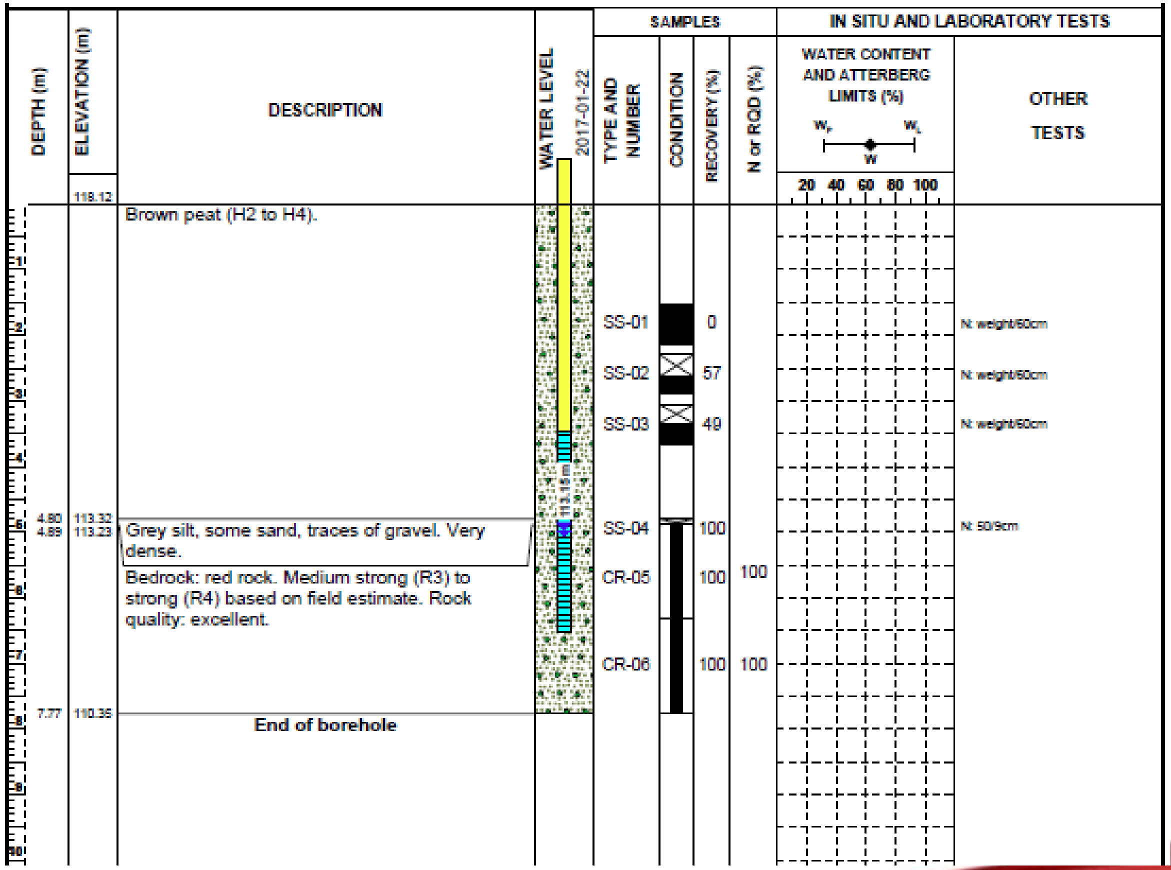
LOWER CHURCHILL PROJECT

Subsurface Challenges

- Originally specified foundations experienced construction issues
  - Variable bedrock; fluctuating thicknesses of soft soils; shallow groundwater; soft, surficial soils lacking bearing support
- **Grillage Foundations:** Rely on a relatively shallow, dense bearing stratum
- **Driven Piles:** Problematic when shallow bedrock is encountered
- Ambiguity in bog depth and bedrock contact elevation, in combination with adverse site conditions for large excavation and pile driving equipment, led to numerous foundation delays during the early stages of the project



LOWER CHURCHILL PROJECT

Micropile Alternative

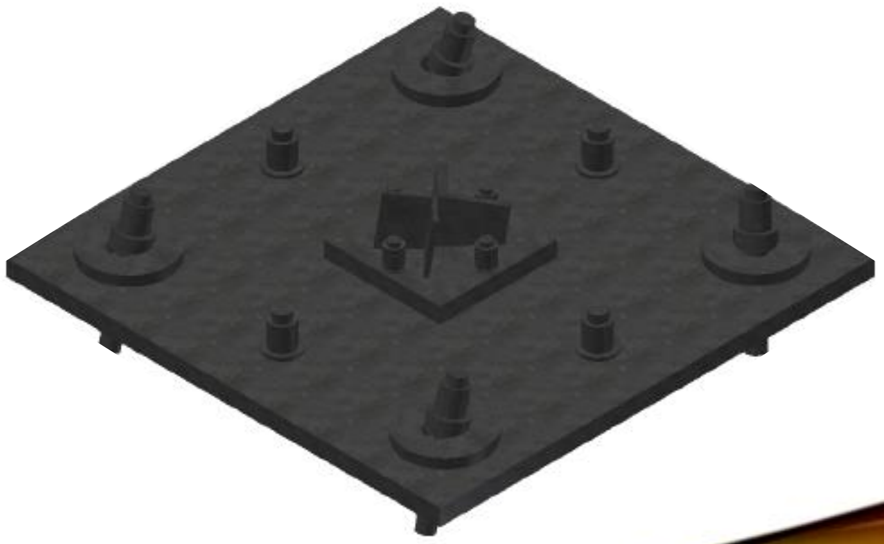
- Micropile designs developed to supplement grillage and drilled shaft, and cover any of the following potential conditions:
  1. Cobbles and boulders within overburden material
  2. Variable depth to bedrock between structures and within structure footprints
  3. Soft overburden overlying relatively shallow hard bedrock
  4. Soft surface conditions during periods prior to freezing and during thawing
- Hybrid foundations were also developed for sites requiring a combination of foundation types

LOWER CHURCHILL PROJECT
Pile Design

- Varying number of micropiles grouped together with a steel cap
- Structure Loads:
    - Lattice structures: Up to 2,100 kN uplift, 2,650 kN compression, and 850 kN shear at each leg
    - Guyed structures: Up to 2,400 kN compression and 292 kN of shear at the center pin
- Detailed foundation schedules created for each site – provided foundation capacities for a range of expected conditions
    - Factored in varying subsurface conditions, adfreeze conditions, and limited geotechnical data
    - Site topography impacted micropile orientation & layout: Custom lateral resistance models developed

LOWER CHURCHILL PROJECT
Pile Design

- 3, 4, 6 and 8 pile configurations developed - design selection made during construction
  - Maximum axial pile design loads 661-1216 kN
- Guyed structure center pin foundations: Circular array of battered piles
- Lattice structure foundations: Square layouts, vertical and battered piles
- Steel caps utilized for both: 7-9.5 cm thickness



LOWER CHURCHILL PROJECT
Construction

Access

- Rugged terrain created challenges
  - Winter: Roads were often created through more than 3 m of snow
  - Remining Seasons: Rig mats used to support equipment

Installation

- Same patented field characterization and proof testing from the Koolau-Wailupe project was employed
- Designs were tailored to the installing contractor's equipment to create additional efficiencies

Weather

- Temperatures were frequently close to -40°C

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LOWER CHURCHILL PROJECT
Completion

CONCLUSIONS & IMPLICATIONS

- As demand for electricity grows, transmission projects will push into more remote areas that need unique foundation solutions
- Portability of equipment and materials are a significant advantage of micropiles over other deep foundation types
- Adaptability of micropiles to changing site conditions is critical to projects with little Geotech information or elevated subsurface risk
- Micropiles combined with steel caps eliminates the need for concrete delivery to remote and difficult access sites, improving safety and reducing construction schedule
- Much can be learned by examining foundation design and construction in other parts of the world – ISM is a great resource in this effort

QUESTIONS?