Current Design & Construction Practices For Micropile Supported Foundations of Electrical Transmission Structures in North America

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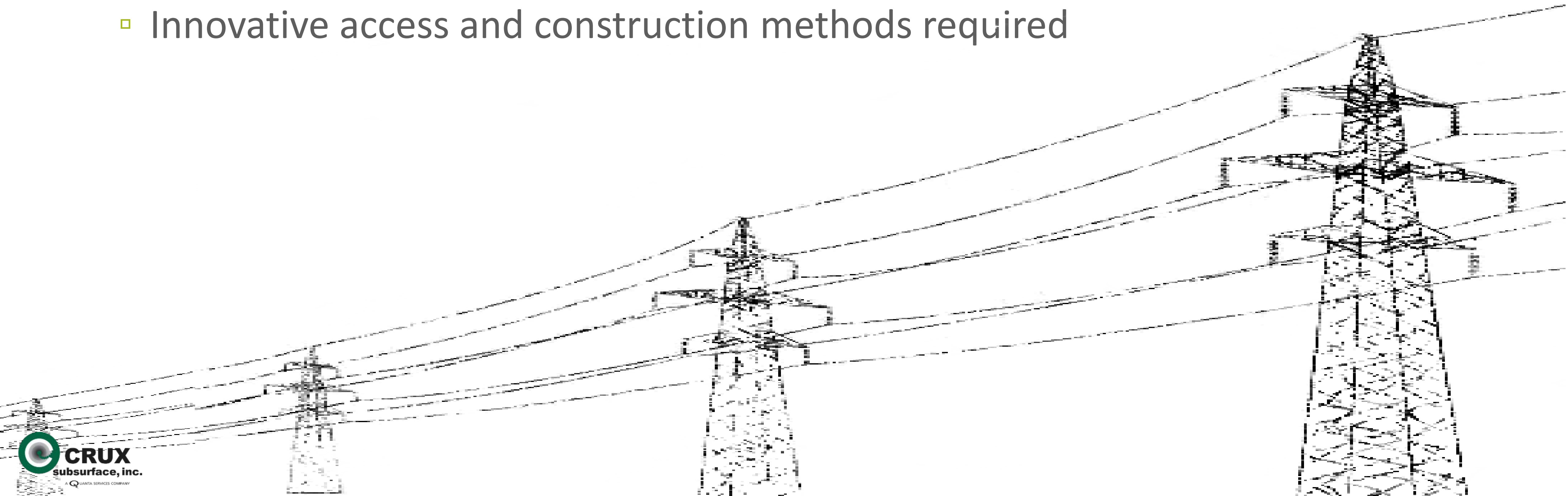
Electrical Transmission Market

- More than 35% increase in demand over last 20 years in North America
- Increased demand for renewable energy sources (Hydro, Wind, Solar)
  - Alignments traverse remote, environmentally sensitive and rugged terrain
  - Innovative access and construction methods required



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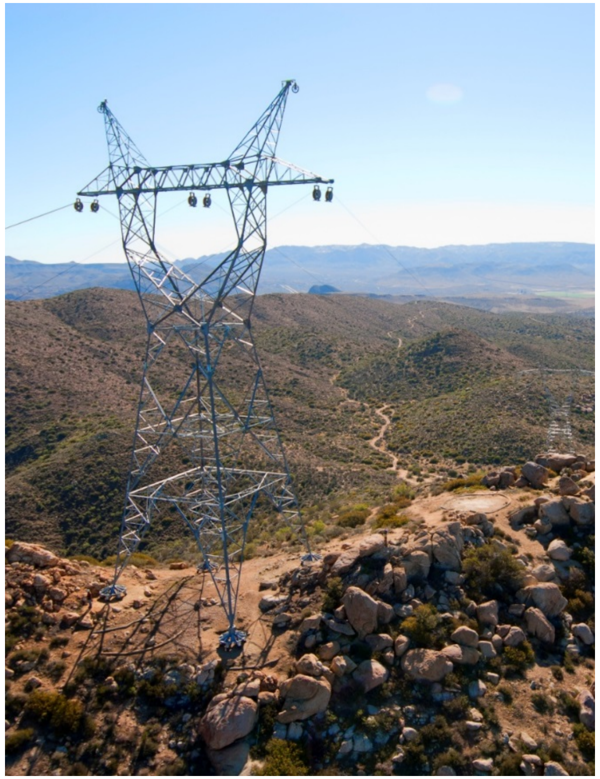
Typical Electrical Structure Types

Tubular Steel Pole



Self-Supporting Lattice

Guyed Lattice

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Foundation Types

- Conventional Transmission Structure Sites
  - Predicated upon conventional access
- Traditional Foundation Types:
  - Drilled Shaft
  - Mat Foundation
  - Grillage
- Cost Effective

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Foundation Types

- Difficult to Access, Environmentally Sensitive Sites, or Challenging Geotechnical Conditions Require Alternative Foundation Options
  - Mountainous Terrain
  - Wetlands
  - Unpredictable geotechnical conditions
  - Sites where road building is not feasible or permitted

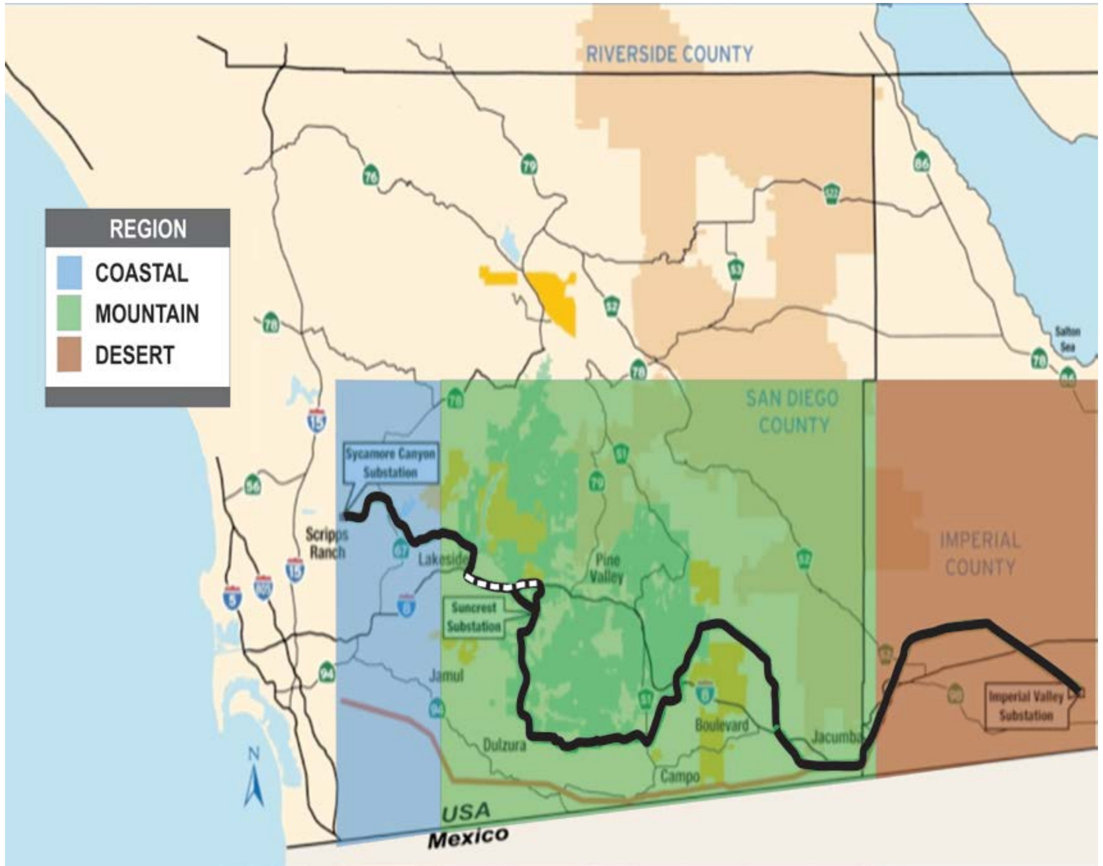
Protected Wetlands

Micropile Foundations

- Micropiles Provide an Ideal Foundation Solution
  - Lightweight ground transportation and helicopter portable equipment and materials
  - Small area of construction impact
  - Adaptable to a wide variety of geotechnical conditions
  - Develop high capacity in tension, compression, and lateral (composite micropiles)

Project Examples

- Sunrise Powerlink Project
  - 188 km, 500 kV alignment
  - California, United States
  - Self supporting structure loads (per leg):
    - 1000 K Compression
    - 900 K Tension
    - 400 K Shear
  - Geotechnical Conditions:
    - Sedimentary deposits overlying bedrock
    - Primarily granitic bedrock with localized volcanic rock
    - Corrosive soils in the coastal area



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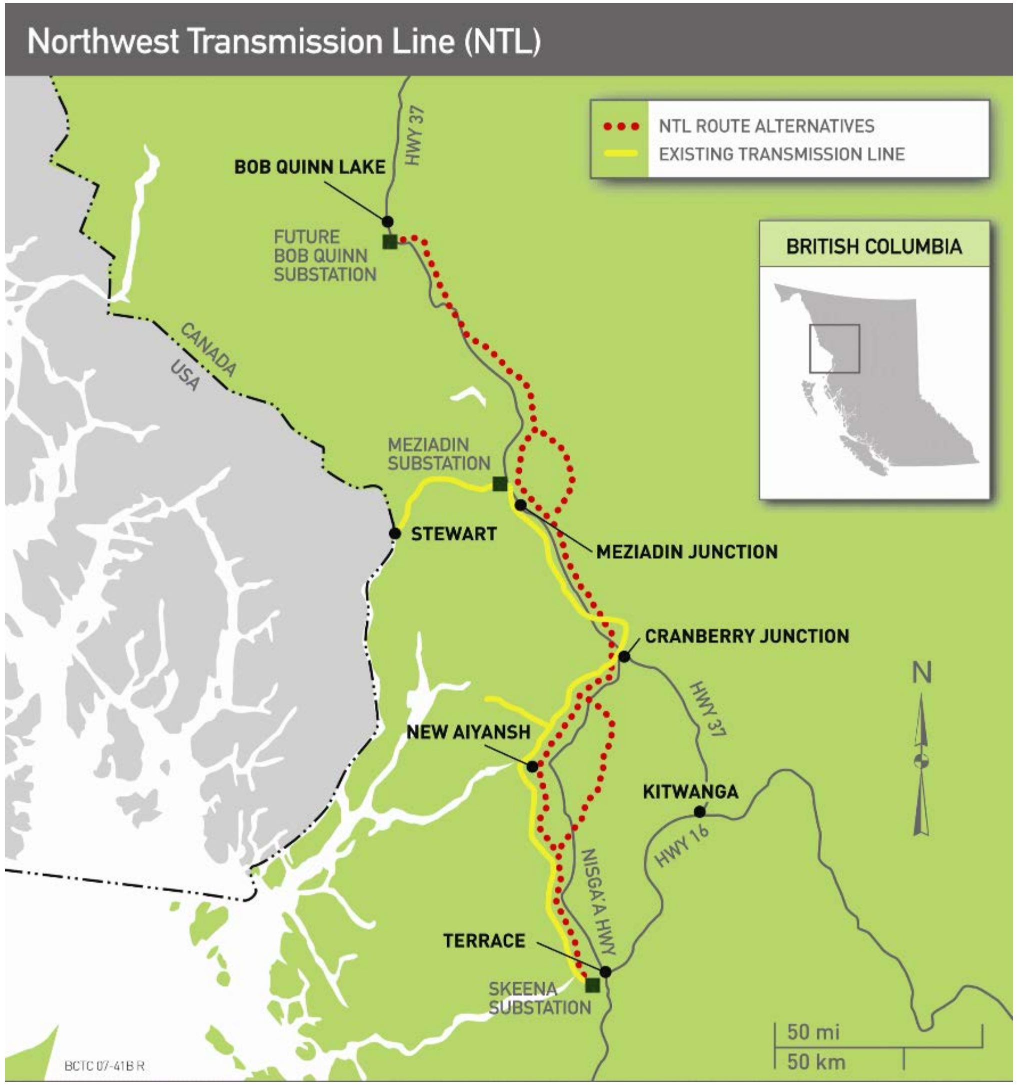
Project Examples

- Northwest Transmission Line
  - 343 km, 287 kV alignment
  - British Columbia, Canada
  - Guyed and self supporting structures
  - Loads (per leg):
    - 400 K compression
    - 350 K tension
    - 140 K shear
  - Geotechnical Conditions:
    - Highly variable depth to rock
    - Fluvial sands/cobbles/boulders overlying glacial till or bedrock
    - Bedrock consisted of medium to fine grained sandstone, siltstone, and shale



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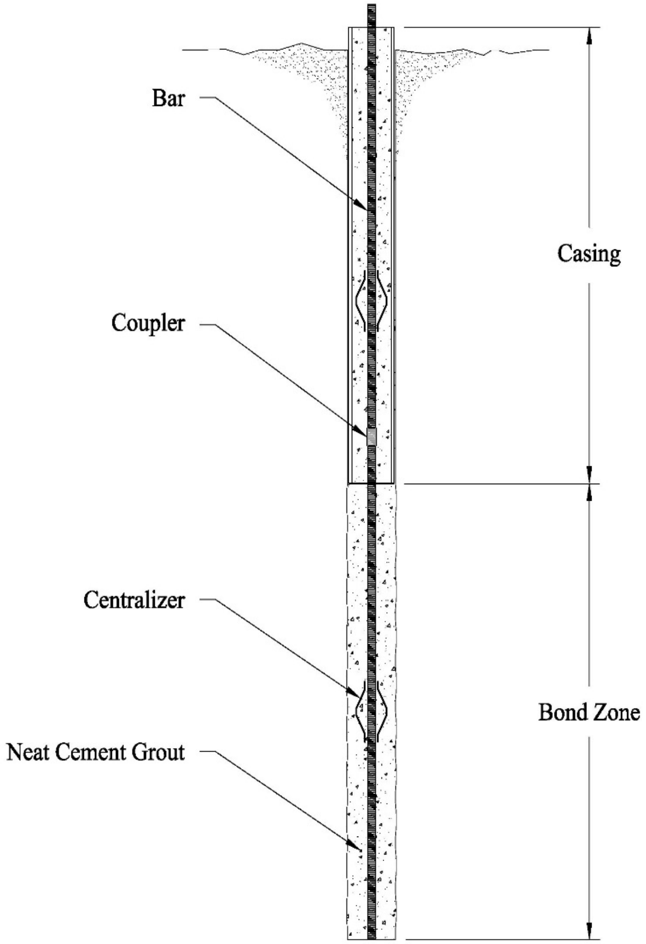
Solution

- Utilize Helicopter Portable Equipment and Materials
  - Drills
  - Platforms
  - High pressure air
  - Testing equipment
  - Grout transfer units
  - Threaded bar and casing
  - Steel pile caps
- Also Beneficial for Light Ground Based Access

Solution

- Composite Micropiles Installed in Circular Array
  - Omni-directional capacity
  - Casing provides flexural resistance and fixity with cap
  - Reinforcing bar and grout provide axial capacity



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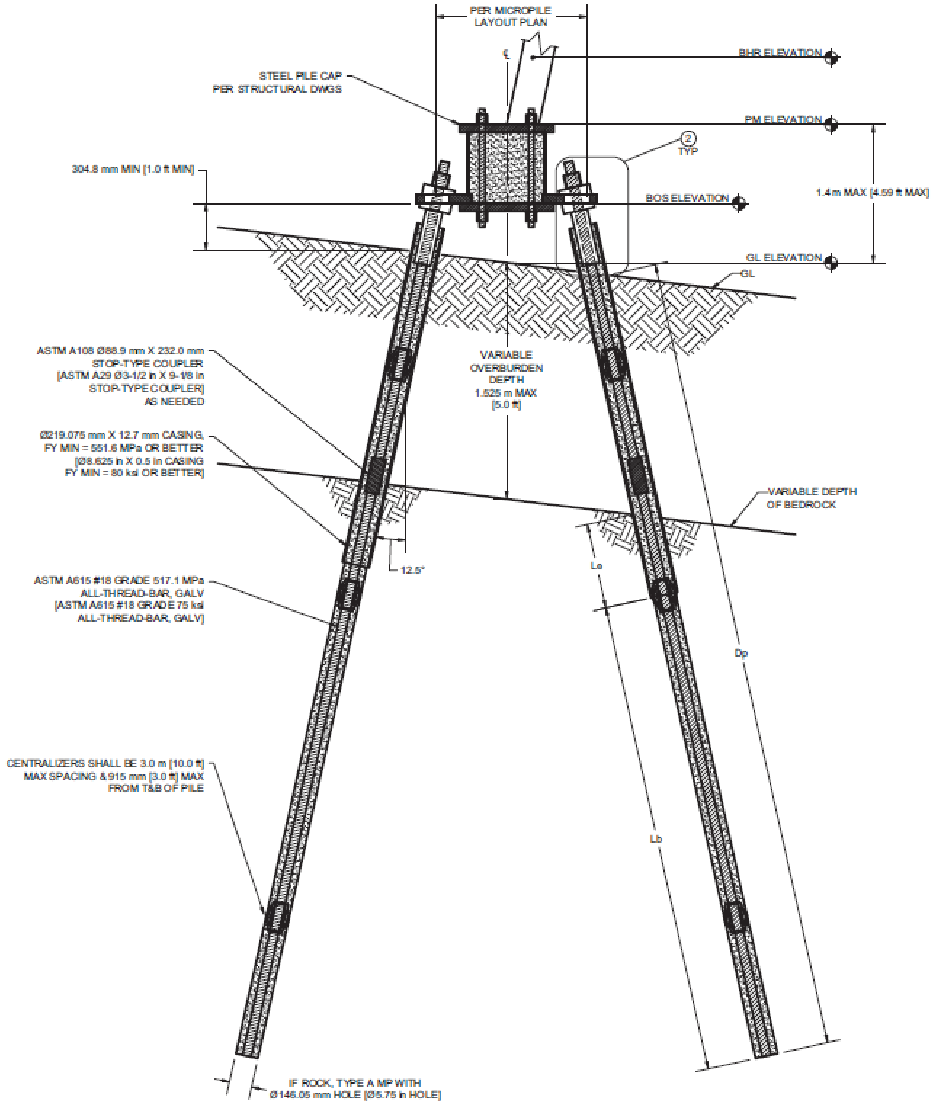
Solution

- Pile Installation and Field Characterization
  - Drilling first pile allows for site characterization (US Patent Pending)
  - Utilize foundation schedule to calibrate installation to design
  - Vary quantity of piles, cased length, and bond length based on site characterization



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Steel Pile Caps

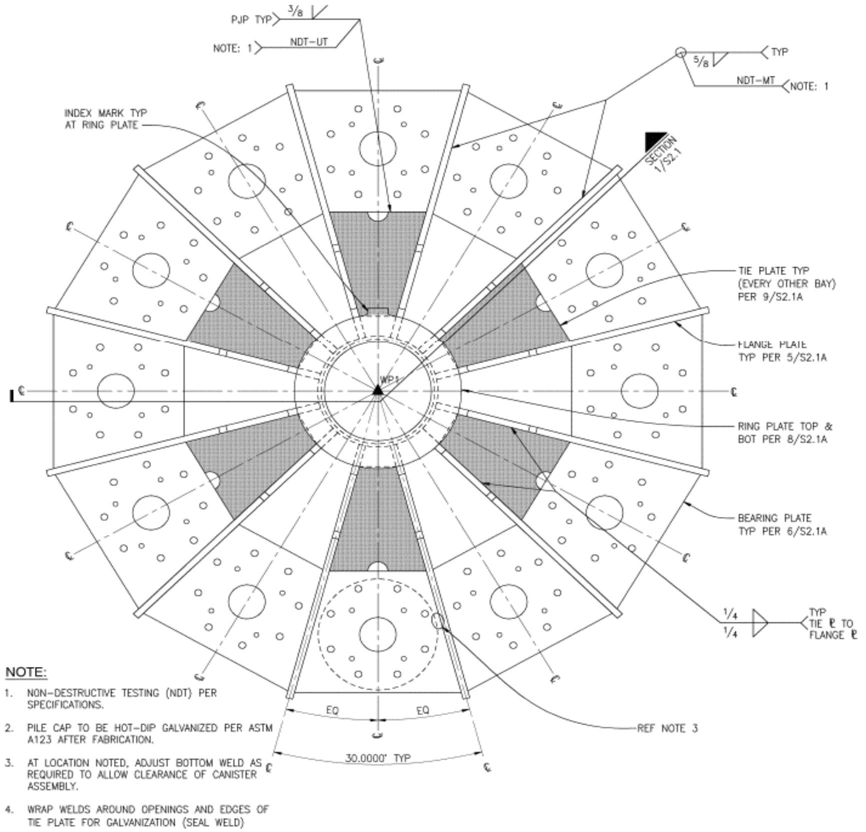
- Steel Pile Caps Introduced to Both Projects as an Alternate

Steel Pile Caps

- Benefits
  - Prefabricated under high level quality control
  - Galvanized
  - All bolted connections
  - Faster construction time
  - Better schedule control
  - Increased project safety
- Challenges
  - Complicated geometry and analysis
  - Fixity with piles – no welding
  - Adaptability with site variable pile quantities
  - Difficult to galvanize – thermal stresses

Steel Pile Caps

- Steel Cap Drawings



- Welded series of plates
- Omni-directional variation Between 12, 6, 4, and 3 pile configurations
- Fixity between pile and cap
- Worked with fabricator to develop galvanization process and weld inspection protocol

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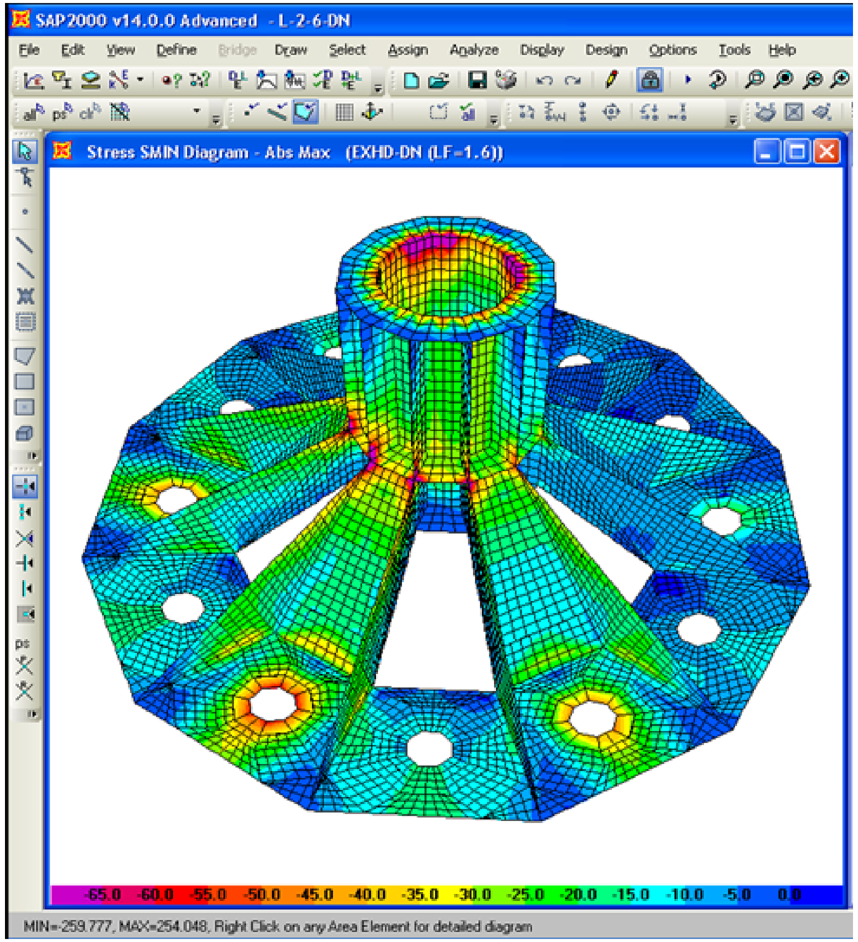
Steel Pile Caps

- Finite Element Analysis



- Shell elements
- Review of peak stresses and deflections
- Review of potential buckling of plates
- Estimate of foundation rotation
- More accurate weld design
- Allowed for design refinement and reduced cap weight

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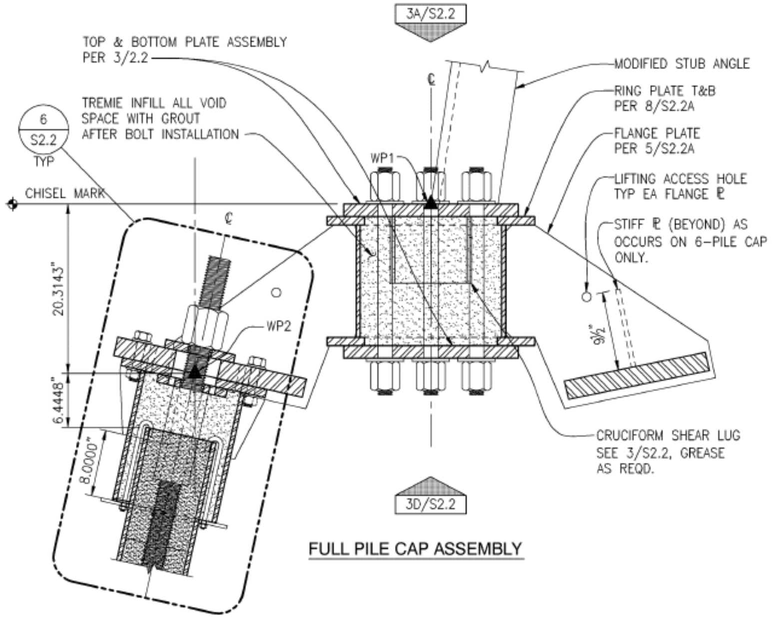
Steel Pile Caps

- Finite Element Analysis

- Conflict resolution
- Shop/fabrication drawings



Steel Pile Caps

- Full Scale Load Test
  - Calibrate FE model through full scale testing
  - Applied 1000 K compression and 350 K shear simultaneously
  - Resulting deflections closely match FE predictions

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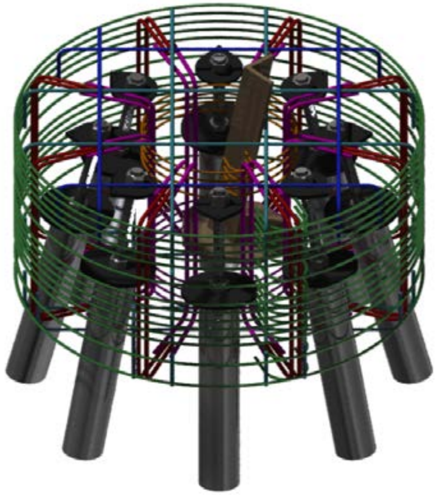
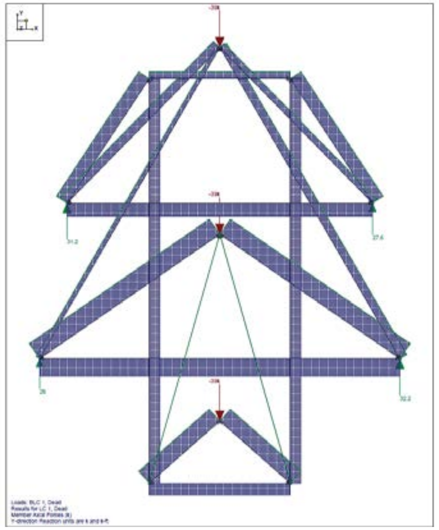
Concrete Pile Caps

- Concrete Caps are utilized when larger rotational capacity is required
- Benefits
  - More efficiently support larger overturning loads
  - Fixity between cap and pile easier to attain
  - Corrosion protection by concrete cover
- Challenges
  - Longer construction time
  - Affected by weather
  - Lower QC reliability

Concrete Pile Caps

- Strut and Tie Analysis
  - Caps are controlled by shear failure
  - Compact sections with little flexure
  - Model concrete section as a system of compression struts and tension ties
  - More desirable distribution of reinforcing





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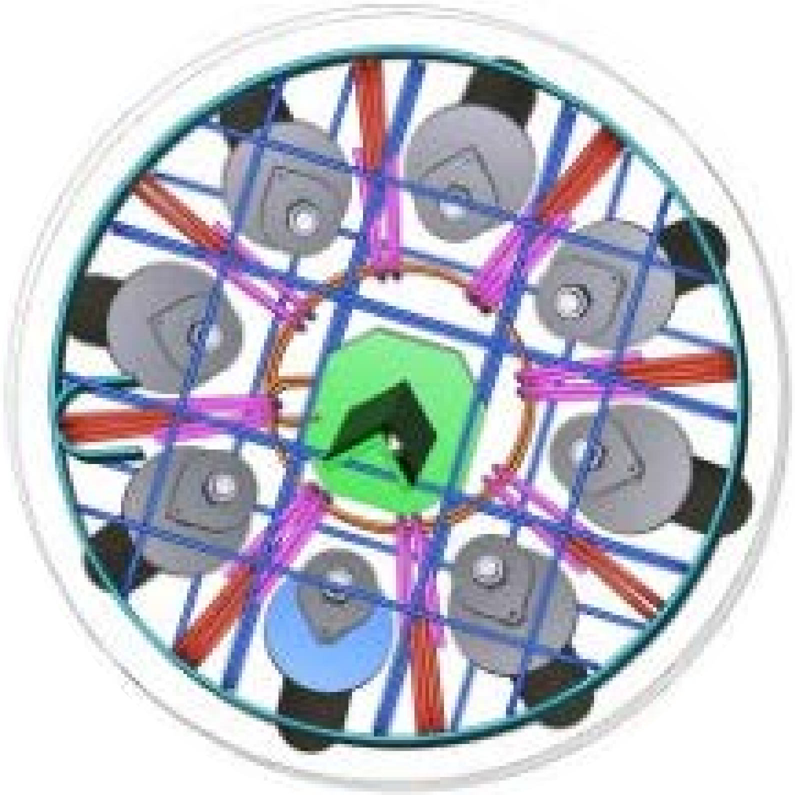
Concrete Pile Caps

- Conflict Resolution
  - 3D Modeling of Reinforcing and Micropiles
  - Determine tolerance between components
  - Develop shop drawings for reinforcing fabrication



Concluding Observations

- Traditional foundation methods will continue to be advantageous in conventional access environments
- Transmission projects will continue to be forced into areas with non-conventional access or challenging geotechnical conditions
- Miropiles are a proven and reliable foundation solution for a variety of non-conventional construction applications
- Continued innovation in micropile design and cap construction will broaden the applications for micropile construction

Questions and Answers