Geotechnical Design

Application to Engineered Aquatic Structures

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Audience Questions

Profession:

- Engineer
- Geologist
- Hydrologist
- Biologist
- Marketing
- Other…

Type of Work:

- River/Stream Restoration
- Civil
- Environmental
- Other…

Introduction

- What geotechs do?
  - Match appropriate pile/anchor type to site/project constraints
  - Match geotech components to achieve desired performance
- We hope Hart Crowser's experience (35+ yrs) will save you some trouble

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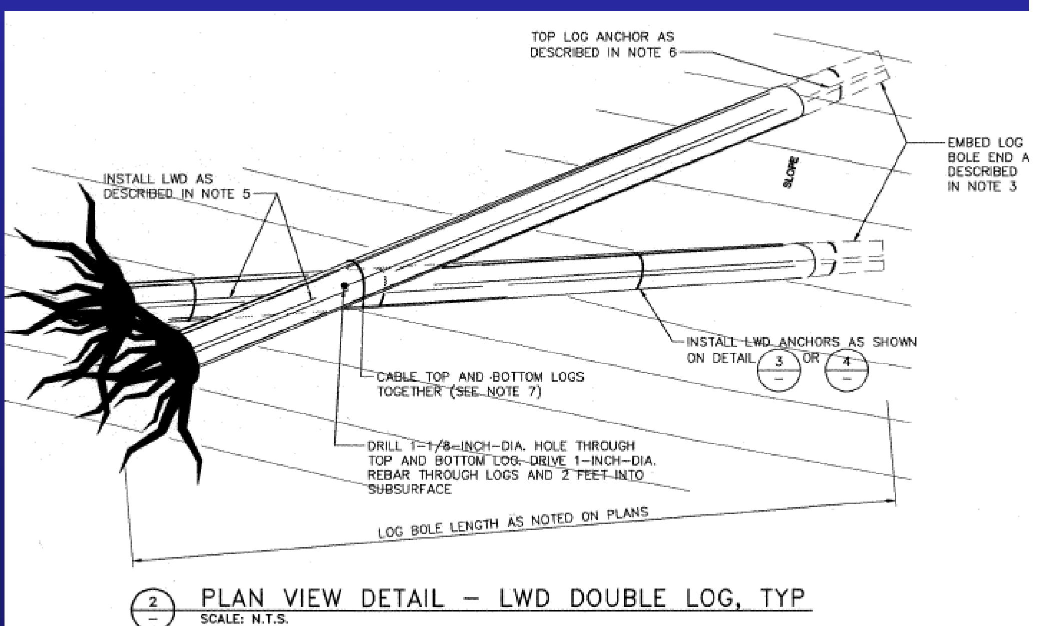
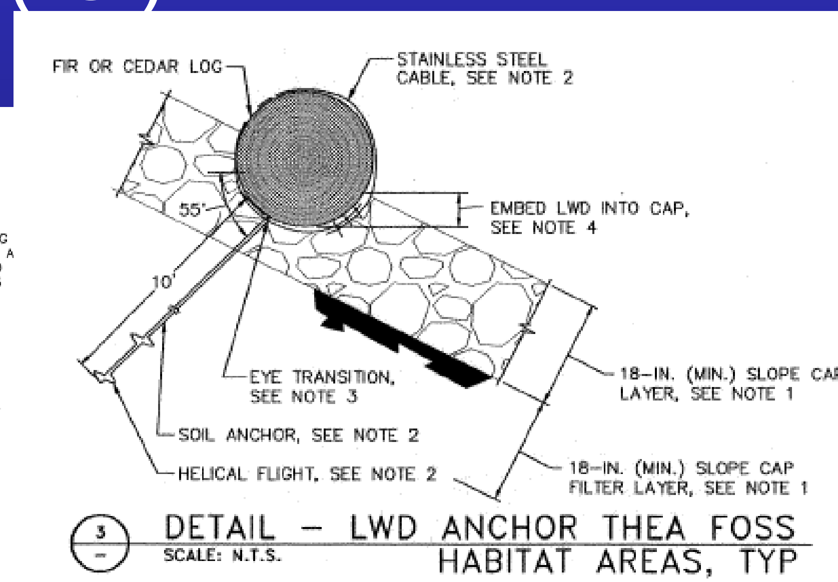
Application to Aquatic Structures

- Application to engineered log jams (ELJ), wood reinforced flood plain structures (WRFPS), LWD anchoring, etc.
  - Piles (main focus today)
  - Ground Anchors
- Application to stream restoration
  - Mechanically Stabilized Earth (MSE)





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Why Piles or Anchors?

- Mitigate settlements in compressible soils
  - Soft clay, silt, organic soil, or peat
  - Random fill
- Transfer loads deeper than scour depth
- Mitigate effects of soil liquefaction
  - Saturated, loose sand or non- to low-plasticity silt
- Does project need piles or anchors???

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Soil Exploration

- Borings with Standard Penetration Test (SPT) (rough costs ~ $20 to $30/ft plus laboratory and observation costs)
- Cone Penetration Test (rough costs ~ $11 to $15 / ft add $9/ft for seismic)
- Hand Auger Boring
- Test Pits
- Sonic Drilling
- Rock Coring

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SPT Procedure

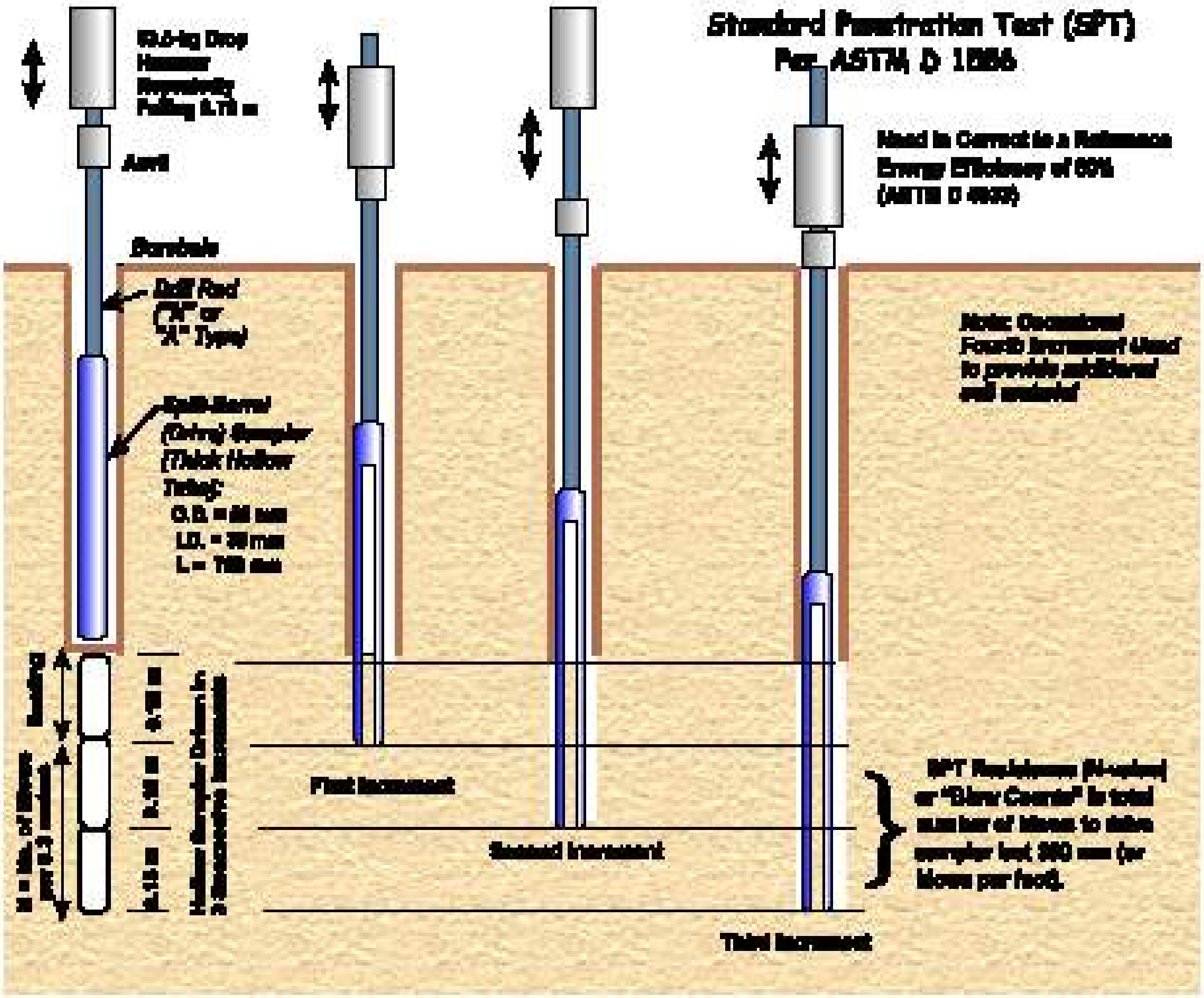

Figure 5-3. Sequence of Driving Split-Barrel Sampler During the Standard Penetration Test.

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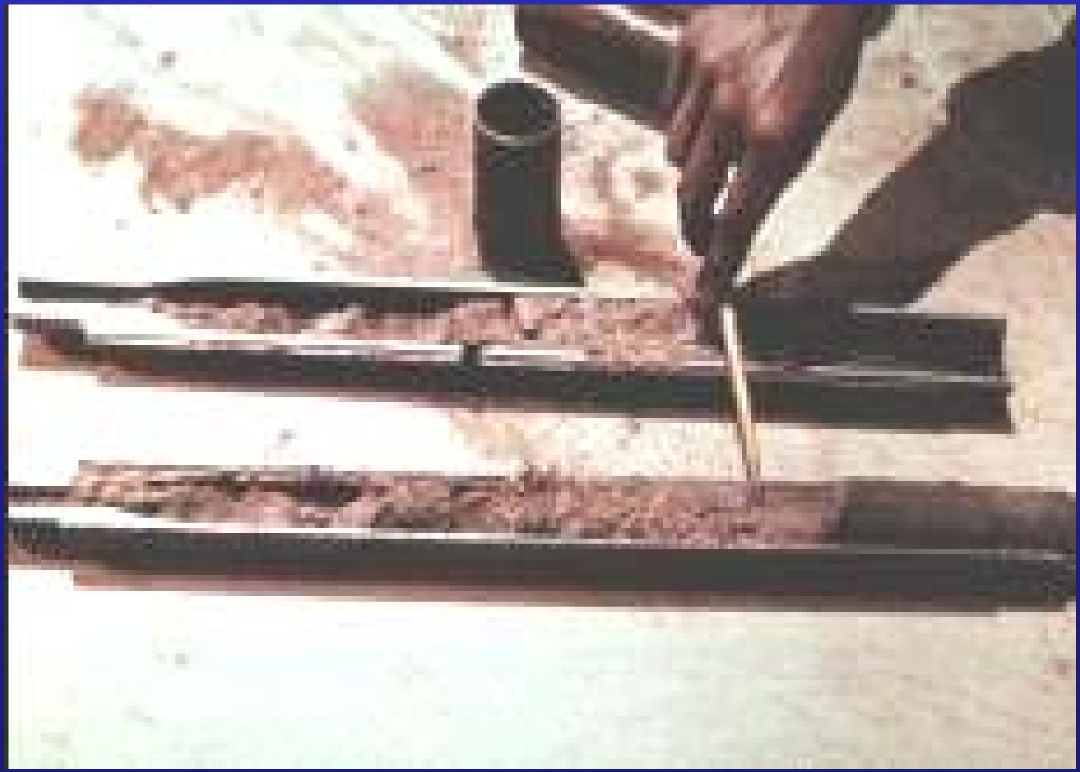
Standard Penetration Testing

- Standard Penetration Test (SPT, ASTM D1586)
  - 140 pound hammer with a 30-inch drop
  - Typically samples collected every 2.5 to 5 feet
  - Record blows for three 6-inch intervals & report values for last 12 inches



Hollow Stem Auger Boring (SPT)

- Good for water level determination ATD
- Prone to heave below GWT and more variable blow counts

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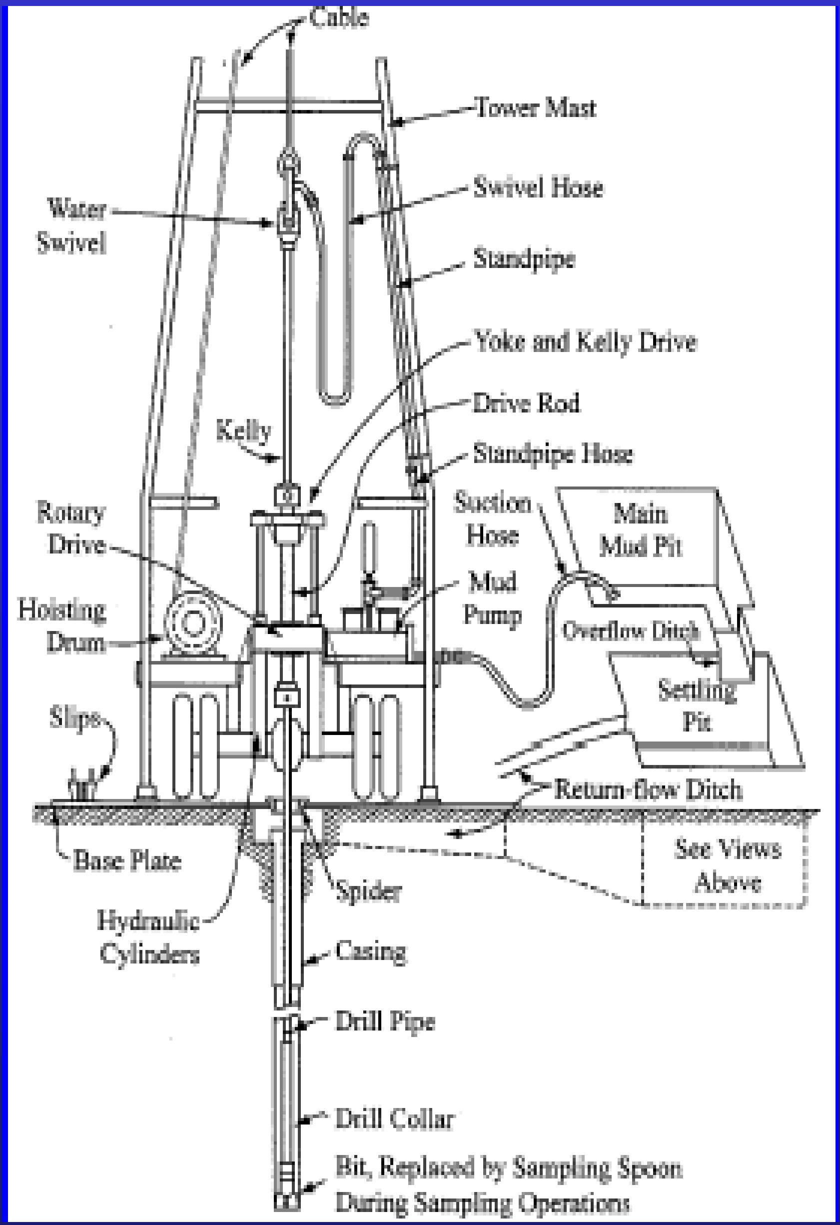
Mud Rotary Boring (SPT)



- Difficult to identify water level
- Drill mud limits heave to obtain better blow counts
- Messy operation

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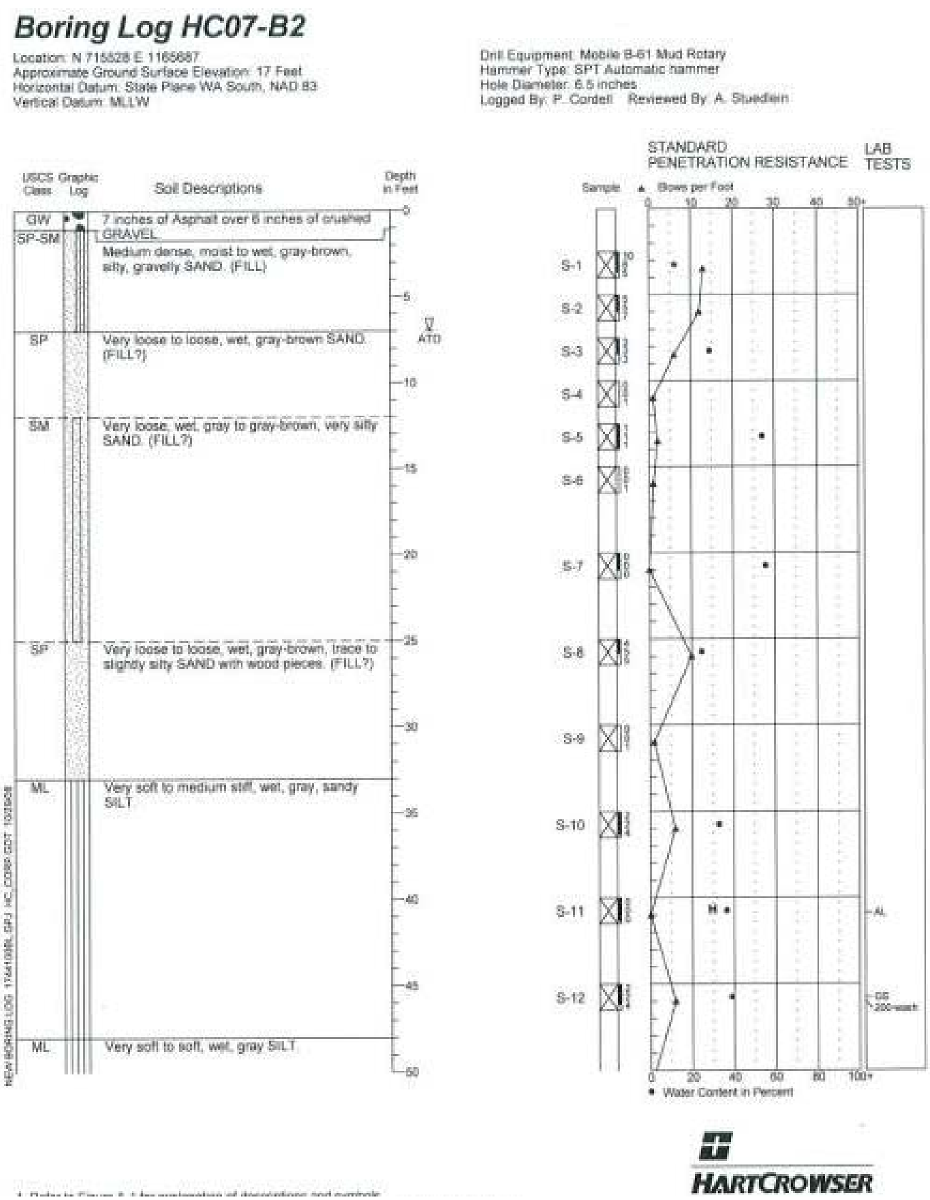
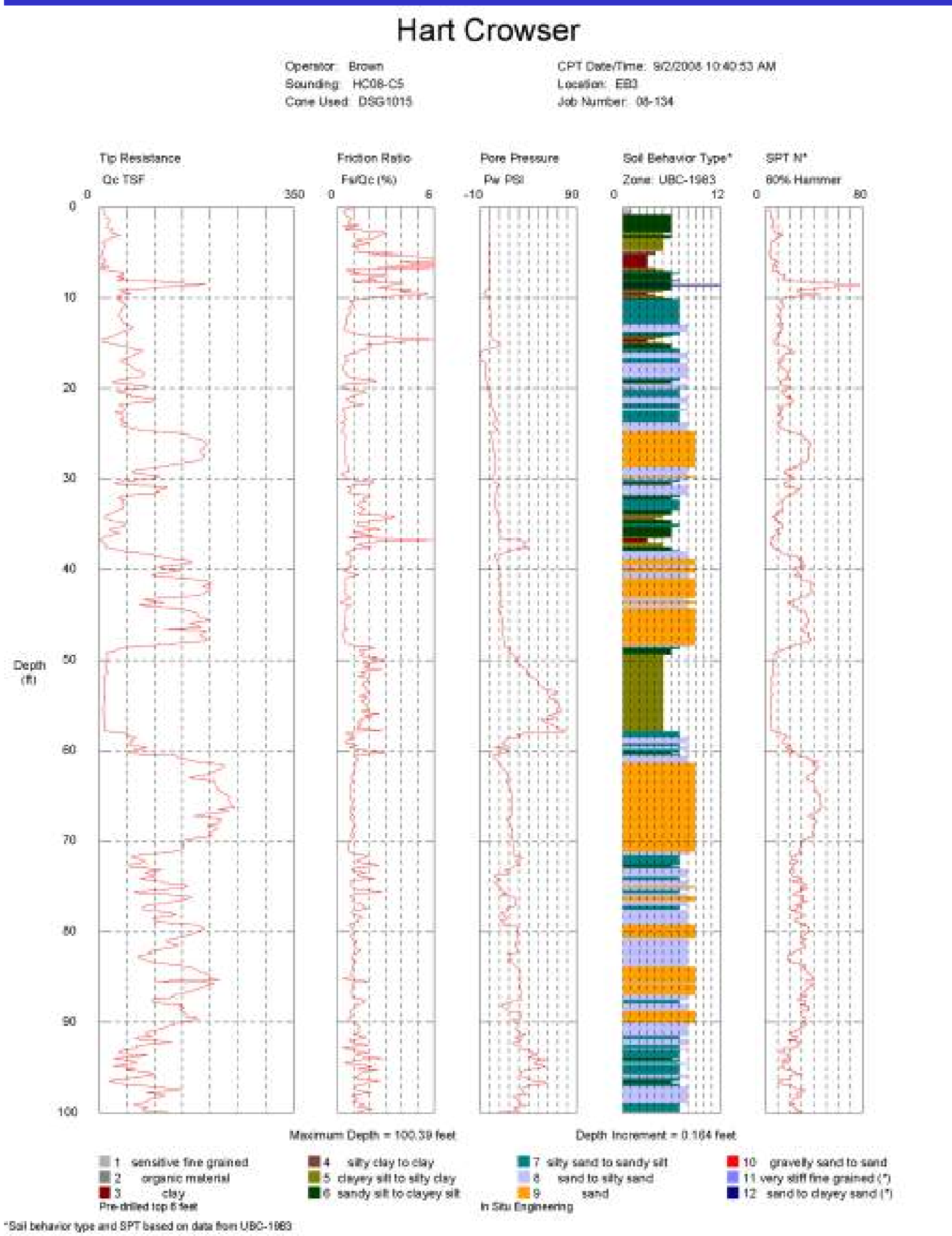
Soil Exploration: SPT



Soil Exploration: CPT



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Hand Augers and Test Pits

- **Hand Augers**
  - **Access to most locations**
  - **Limited depths, no blow counts**
- **Test Pits**
  - **Can see subsurface conditions (caving, seepage, debris cobbles/boulders, things that may impact construction)**
  - **X-section of vertical & horizontal subsurface variation**

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Pile/Anchor Selection

- Ground conditions
- Load & deflection constraints: vertical & lateral
- Vibration and noise impacts
- Space & overhead limitations
- Environmental considerations (corrosion, scour, river dynamics, habitat)
- Construction constraints (schedule, access, etc.)
- Pile $$$

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Pile Types

- **Driven piles**
  - **Timber, steel pipe, precast concrete**
  - **Pin pile**
- **Drilled, cast-in-place piles**
  - **Augercast pile**
  - **Drilled shaft (pier)**
  - **Micropile**
  - **Drilled displacement pile**
- **Others**
  - **Driven grout pile**
  - **Helical anchor**
  - **Duck bill anchor**

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Typical Design Load Capacities

Deep Foundation Type	Diameter (in.)	Axial Capacity (kips)
Driven:		
Steel pipe pile $$ - $$$	12 to 42	100 to 800+
Precast concrete $$$	12 to 36	100 to 1,000+
Timber pile $$	8 to 12 at tip	50 to 70
Pin pile $	2 to 6	4 to 30
Drilled or Cast in Place:		
Drilled shaft $$$	36 to 120+	500 to 3,000+
Augercast pile $$	14 to 36	100 to 300+
Micropile $$	6 to 12	100 to 250
Other:		
Helical Anchors $	2 to 12 shaft 8 to 36 helices	20 to 400

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Aquatic Structure Anchoring Method Comparison

Type	Ability to Penetrate Coarse Alluvium[a]	Installation Equipment	Material Considerations	Construction Impact[b]	Load Transfer Method[c]
Driven Piles:					
Timber Pile	3	Large Crane and Other Equip.	Driving Durability, Rotting	3 – Grading for Crane	C, T, L
Steel HP	1	"	Corrosion	"	"
Steel Pipe	2	"	"	"	"
Pin Pile	5	Bobcat or Small Trackhoe	"	1 – Minimal Grading	C, T
Vibratory/Sonic:					
Timber Pile	3	Trackhoe	Driving Durability, Rotting	1 – Minimal Grading	C, T, L
Steel HP	2	"	Corrosion	"	"
Steel Pipe	2	"	"	"	"
Drilled Anchors:					
Titan®	3	Bobcat or Small Trackhoe and Other Equip.	Corrosion, Brittle Steel	3 – Minimal Grading, Grouting Required	T
Soil Nail, Micro-Pile	3	Track Rig and Other Equip.	Corrosion, Brittle Steel	"	T, C
HEAT anchor®	3	Crane, Trackhoe	"	1 – Minimal Grading	C, T, L
Other Types:					
Helical Anchors	5	Bobcat or Small Trackhoe	Corrosion	1 – Minimal Grading	T, C, L?
Manta Ray	5	"	"	"	T
Deadman	1	Trackhoe and Other Equipment	"	5 – Mass Excavation below Groundwater	"

Notes:

a. Relative ranking from best (1) to worst (5) based on our experience and discussion with a few representative installation contractors.

b. Relative ranking of construction impact from best (1) to worst (5) based on potential impact to river floodplain due to required earthwork and construction methods.

c. = Compression, T = Tension, and L = Lateral.

Typical Design Criteria

- Applied Loads
  - Axial Compression & Uplift
  - Lateral Loads
  - Seismic and Liquefaction
- Allowable Deflection
- Depth to Suitable Bearing Soil
- Other Factors (scour depth, corrosion, impact, etc.)

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Typical Design Process

1. Design/performance criteria, prelim. pile/anchor selection, other factors (i.e., material supply)
2. 1st Geotech Analyses: soil capacity, deflection, construction factors
3. Structural Design: finalize pile type(s), number, length, spacing, structural capacity
4. Pile Load Tests (Optional)
5. 2nd Geotech Analyses: driveability, estimate driving stresses
6. Contractor submits proposed driving equipment for geotech check of driveability & driving stresses (3rd)
7. Pile Installation Tests: before vs. at start of const. (Optional)
8. Construction observations to verify capacity

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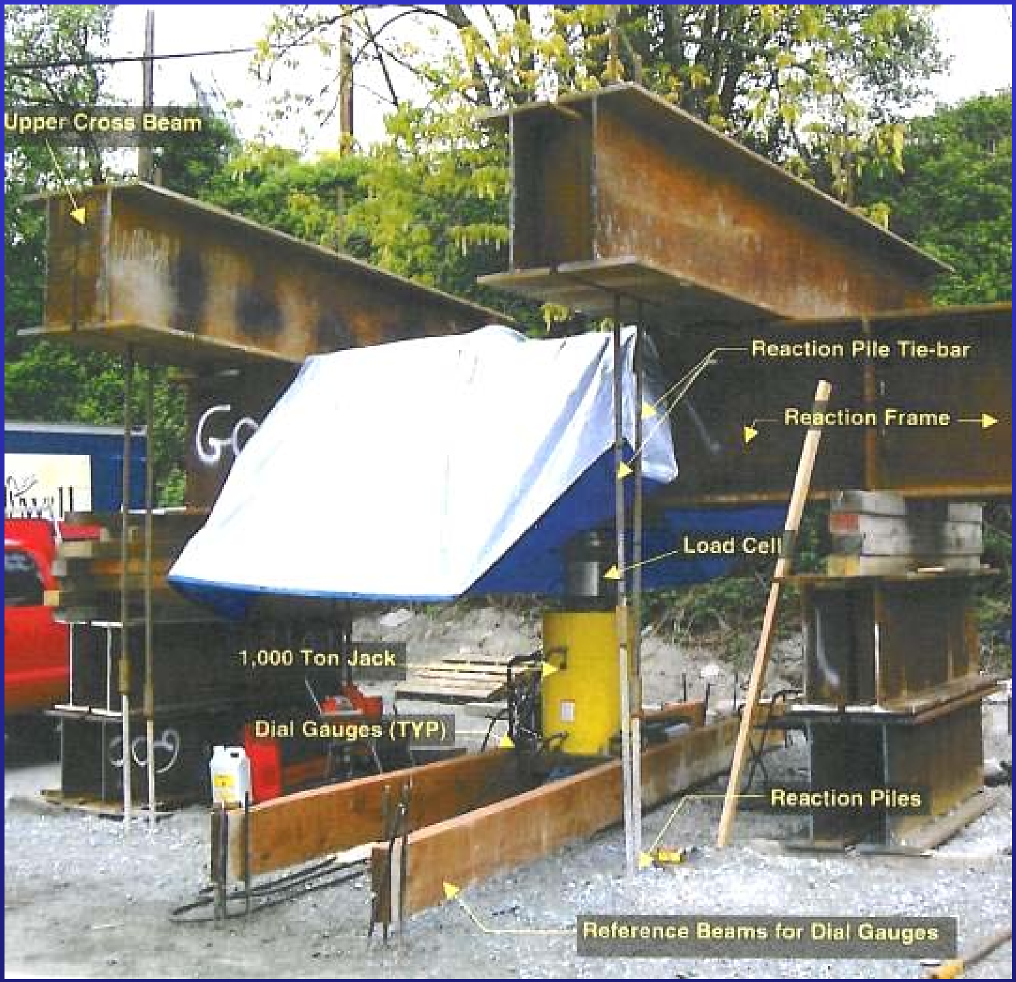
Pile Load Tests



- Why and when?
- Typically for jobs with lots of piles and potential cost savings with higher capacity
- Axial (ASTM D1143)
- Lateral (ASTM D3966)

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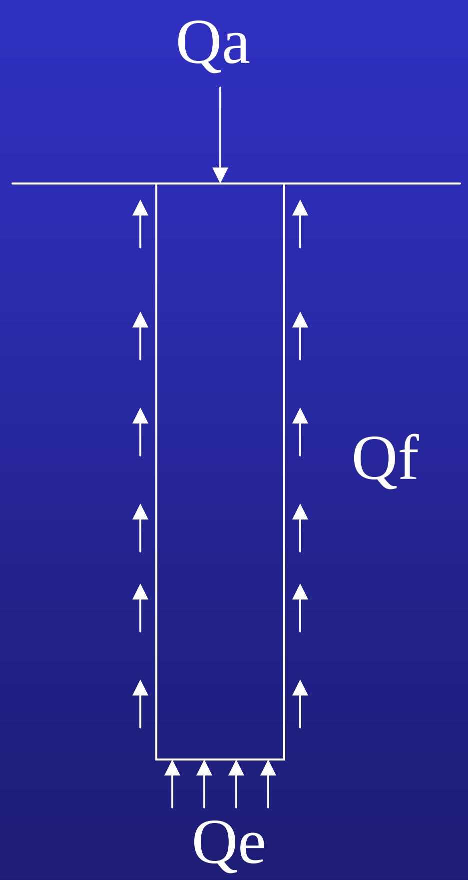
Axial Pile Load Capacity

- End Bearing & Side Friction
  - Qult = Qe + Qf
  - Qa = Qult / F.S.
  - F.S. = 2.0 to 3.0+
- Compressive vs. Uplift
- Settlement
  - Load transfer
  - Pile compression/elongation
  - Soil deformation

- Qe constant with depth
- Qf increases with depth



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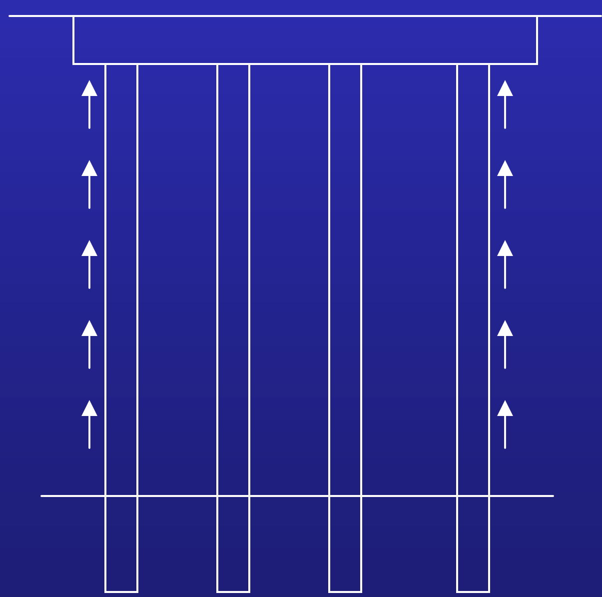
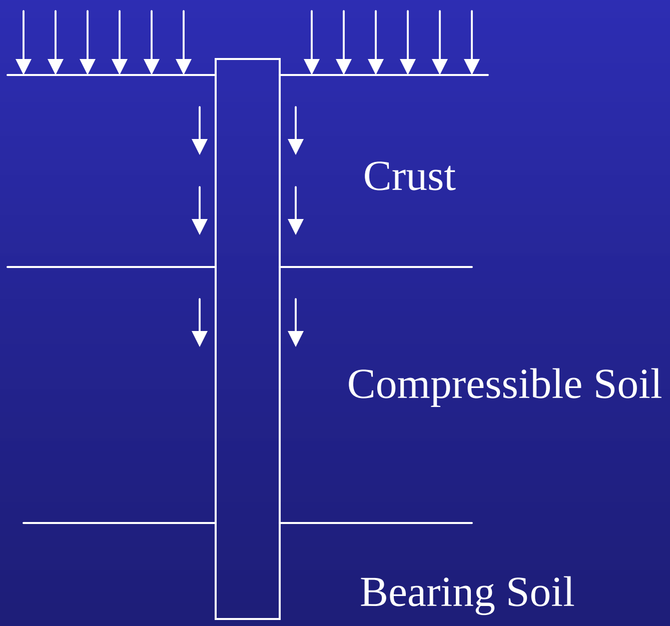
Other Design Considerations

- **Group Effect**



- **Downdrag Force**



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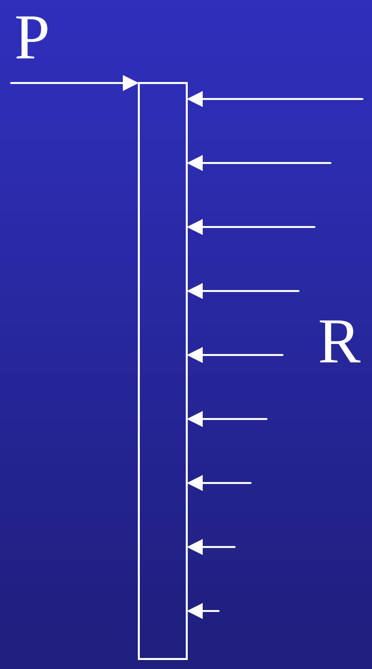
Lateral Pile Capacity

- Near surface soils control lateral performance
- Analysis typically performed on single pile
- Group effects must be considered (3D to 8D)



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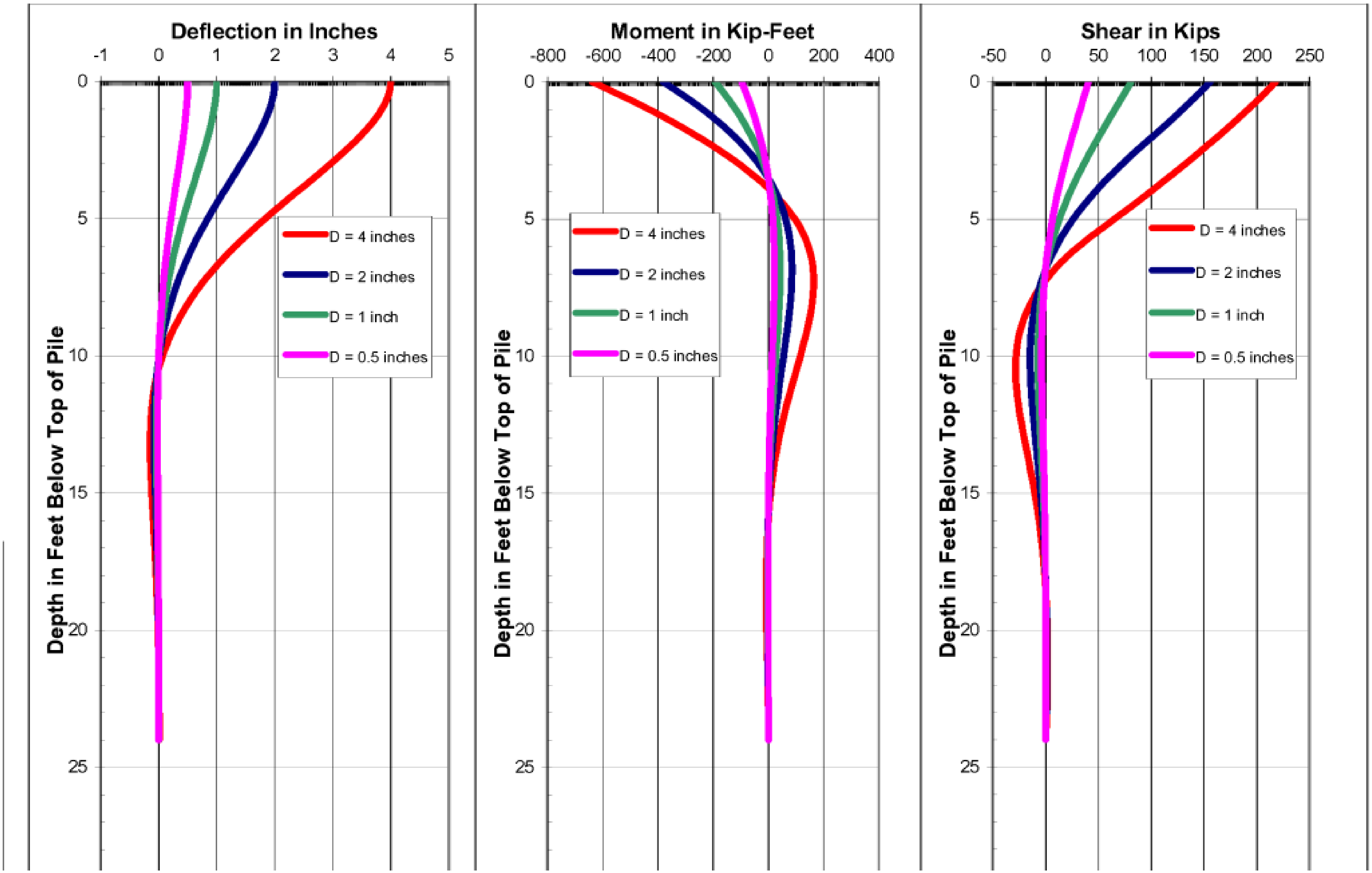
Static LPILE Results: 14-Inch Tapered Individual Timber Pile; Top of Pile 8 feet bgs

Fixed Head (Slope=0); Applied Axial Load = 30 kips



Wave Equation Analysis of Piles

- WEAP is an analysis of pile driveability (Can it be installed?)
- Provides an estimate of pile stresses during driving (Will installation damage the piles?)
- Difficult to estimate pile length without obvious bearing layer

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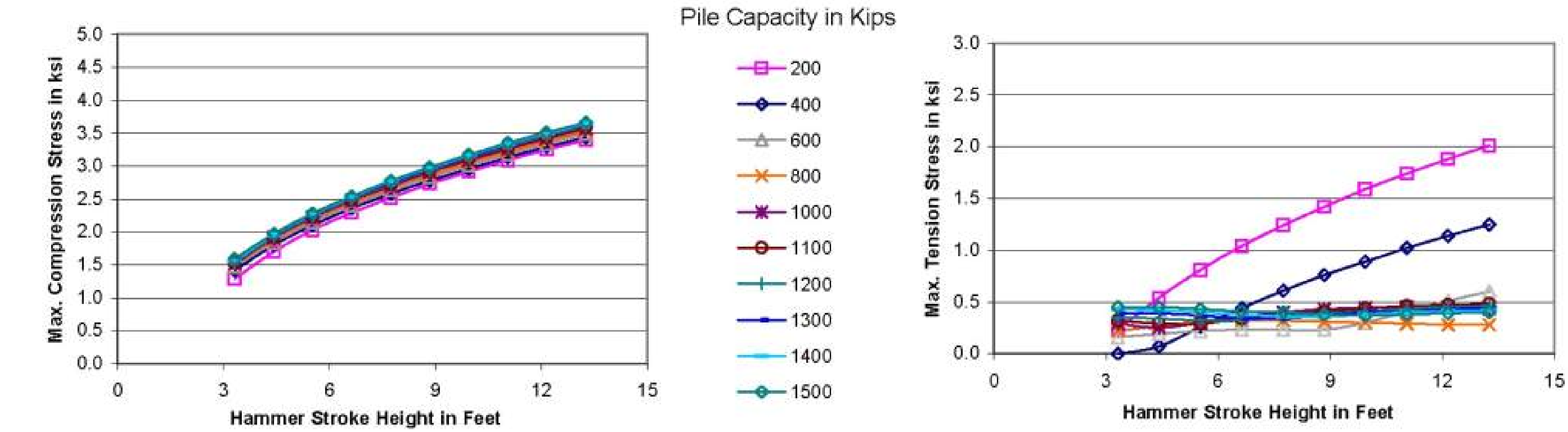
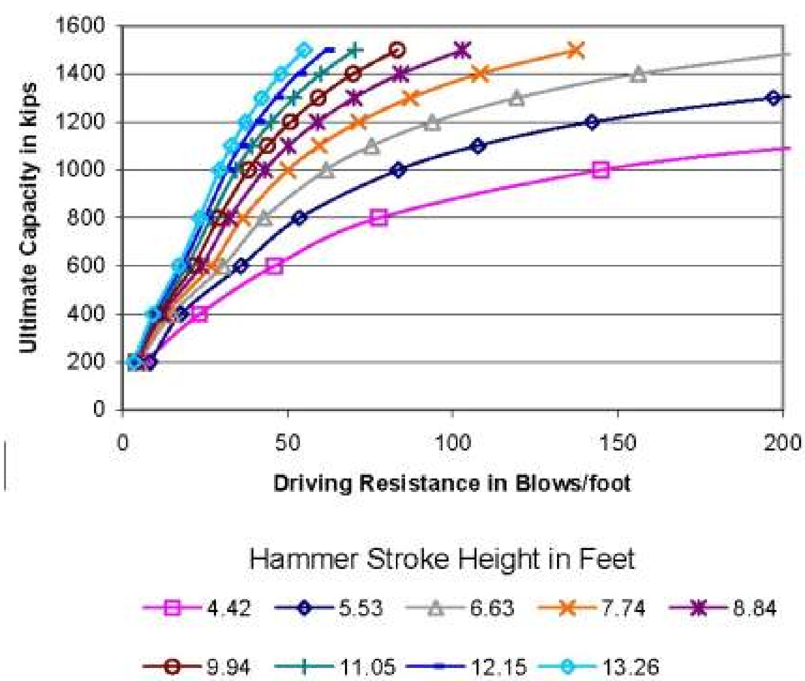
WEAP Analysis

24-inch Octagonal Concrete Pile - D62-22 Hammer





WEAP INPUT PARAMETERS

Pile Data

Material	Concrete
Total Length	105 ft
Penetration	60.2 ft
X-Sect. Area	477.17 in2
Elast. Modulus	5000 ksi
Spec. Weight	150.2 pcf
Perimeter	6.627 ft
Strength (f'c)	8 ksi

Pile Cushion

Thickness	12 in
Area	477.17 in2
Elast. Modulus	60 ksi
C.O.R.	0.5

Hammer	Delmag 62-22
Helmut Weight	6.6 kips
Efficiency	0.8

Hammer Cushion

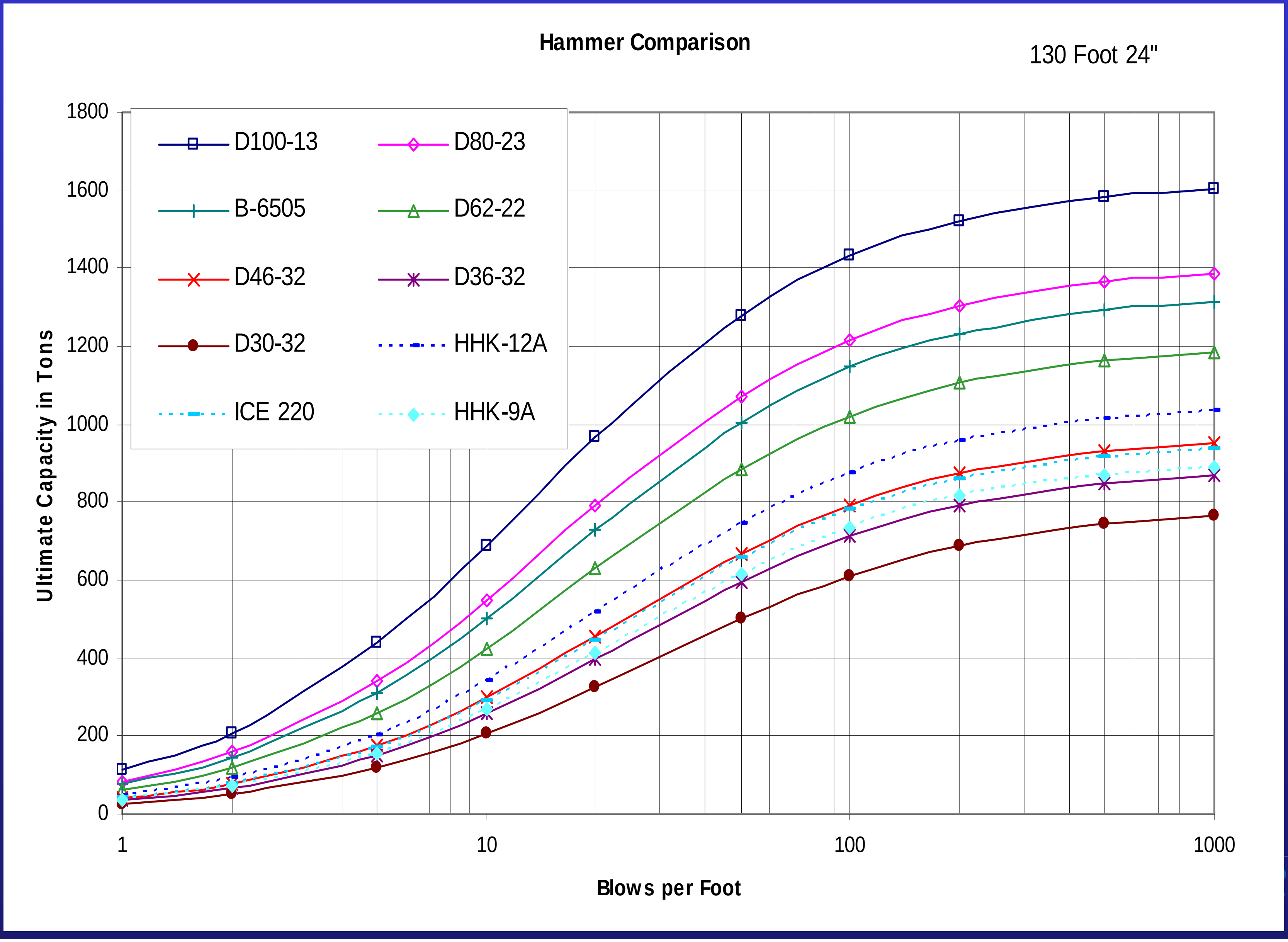
Thickness	3.5 in
Area	415 in2
Elast Modulus	470 ksi
C.O.R.	0.8

Soil Parameters

	Skin	Toe
Quake	0.1	0.2
Damping	0.05	0.15

Shaft Resist.	50%

Pile Driving Equations



Driven Pile Construction Observation

- Inspection: pile driving criteria
  - Plumbness or batter angle
  - Load capacity: blows per foot (bpf)
  - Hammer energy: blows per minute (bpm)
  - Driving stresses: Pile Driving Analyzer (PDA)
  - Pile capacity from CAPWAP
  - Restrike & set up time

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Typical Construction Problems

- Refusal vs. Apparent Refusal:
  - Obstructions (logs, boulders, etc.)
  - Need for driving tip
  - Undersized hammer
  - Shallow high resistance layer
- Damaged Pile
  - Overstressed pile
  - "Broomed" top or bottom of timber pile
  - Improper equipment or hammer-pile alignment

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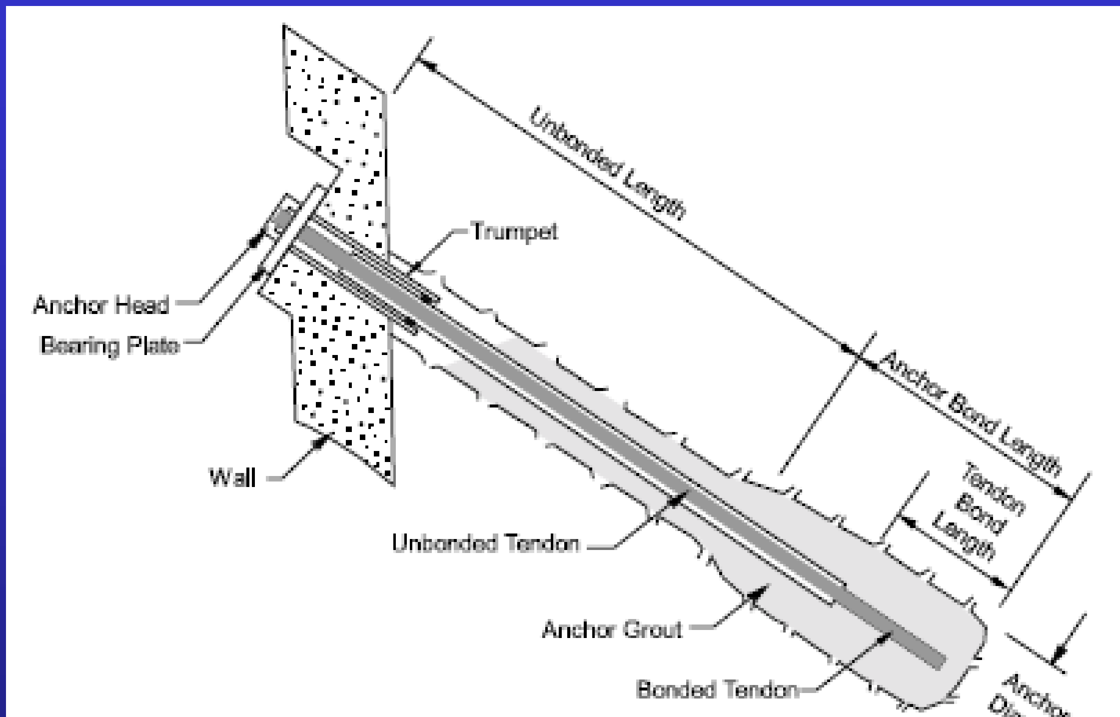
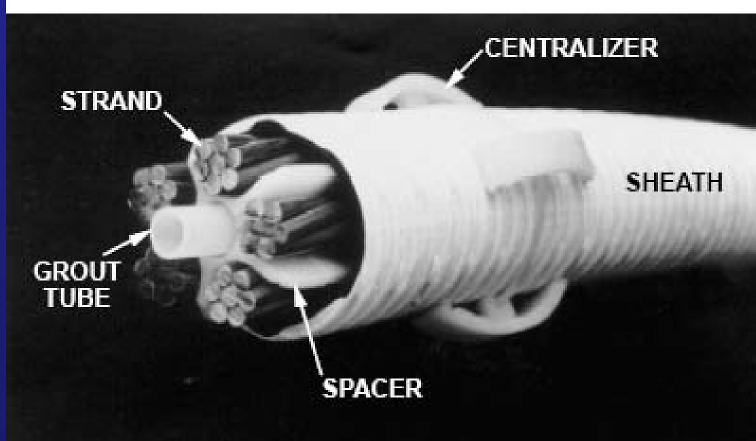
Does geotechnical input really matter?...

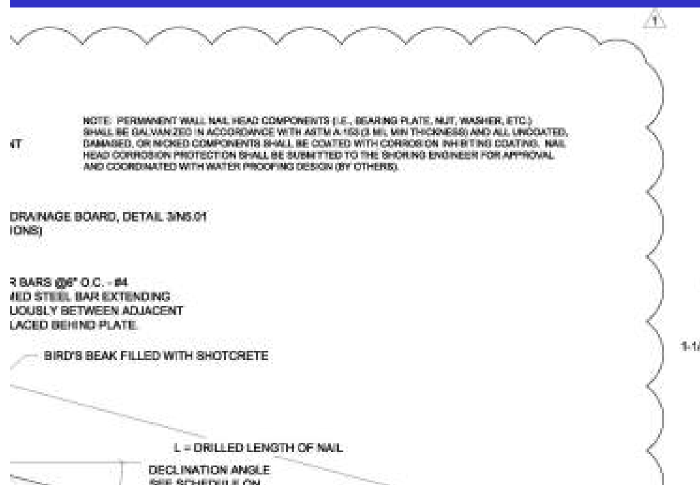
Anchor Details

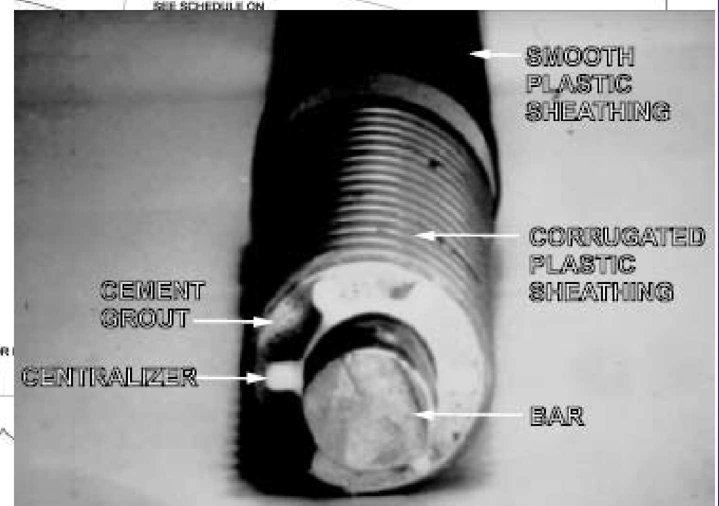
Tieback





Soil Nail





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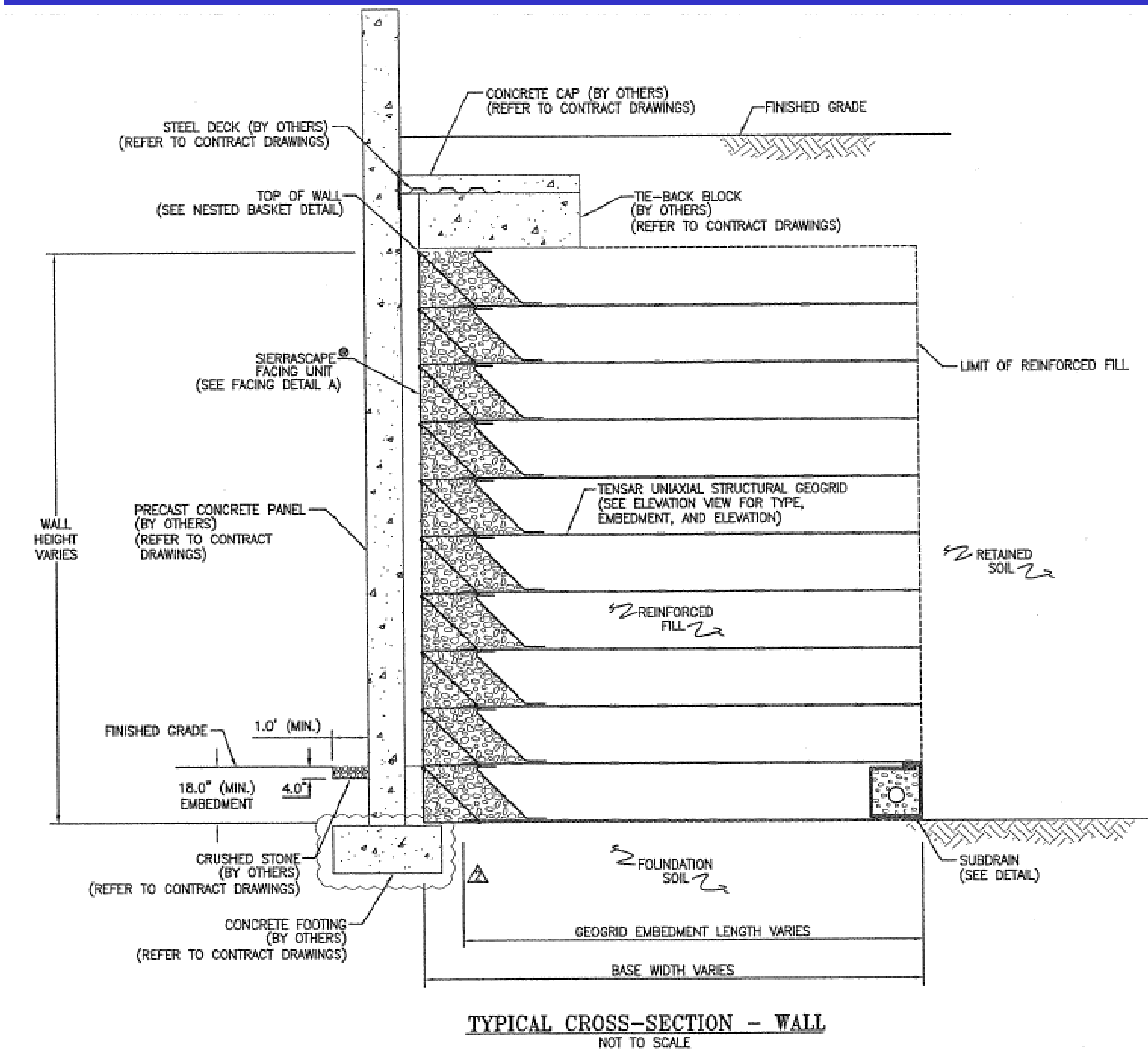
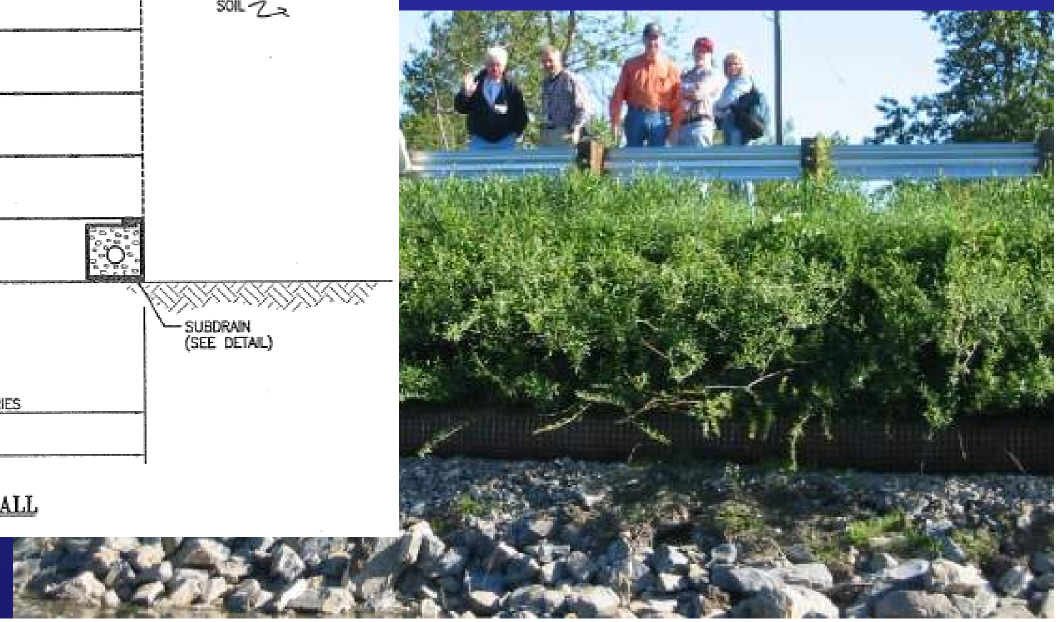
Mechanically Stabilized Earth



- **MSE design**
- **Vegetated MSE**
- **Hybrid vegetated riprap/ vegetated MSE design**



HC Applications of Geotechnical Engineering

- Marine Geotechnical Engineering and Seismic Analysis
- Embankments/Slope Stabilization
- Landslide Evaluation
- Ground Improvement
- Excavation Shoring
- Transportation Projects

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HC Applications of Geotechnical Engineering

- Habitat mitigation geotechnical support (upland, nearshore, offshore)
- Confined aquatic disposal/nearshore fills
- Dredge material characterization, permitting, disposal, reuse, design, and monitoring
- Offshore exploration, drilling, and sampling
- Shoreline protection
- Abandoned mine reclamation

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Other HC Strengths
Natural Resources

- **Fisheries Science**
  - **Freshwater-dams, forestry, roads**
  - **Marine-port and marina facilities, spills, dredging**
- **Aquatic Biology**
  - **Mines, remediation, marine structures**
- **Wetlands**

Intertidal Sampling

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Other HC Strengths
Natural Resources

- Watershed Analysis
- Habitat Restoration
  - Wetland offsets/banking
  - Stream channel relocation
- Permit Development and Support
  - ESA, CWA, NEPA
  - State permits

Ketchikan Airport
Stream Realignment, AK

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Other HC Strengths Environmental Remediation

Richmond Beach Terminal, Seattle, WA

- **Site Assessments**
- **Remedial Investigations & Feasibility Studies**
- **Regulatory Compliance Strategies**
- **Cleanup Implementation**

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Other HC Strengths
Environmental Remediation

- Sediment Sampling and Analysis
- Hydrogeology / Geology
- Environmental Regulatory Support
- Mine Restoration

Thank You!

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CAPWAP

Initial Drive:

Skin = 200 kips

End = 300 kips

TOTAL = 500 kips

Restrike:

Skin = 400 kips

End = 200 kips

TOTAL = 600 kips

REAL TOTAL = 700 kips

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