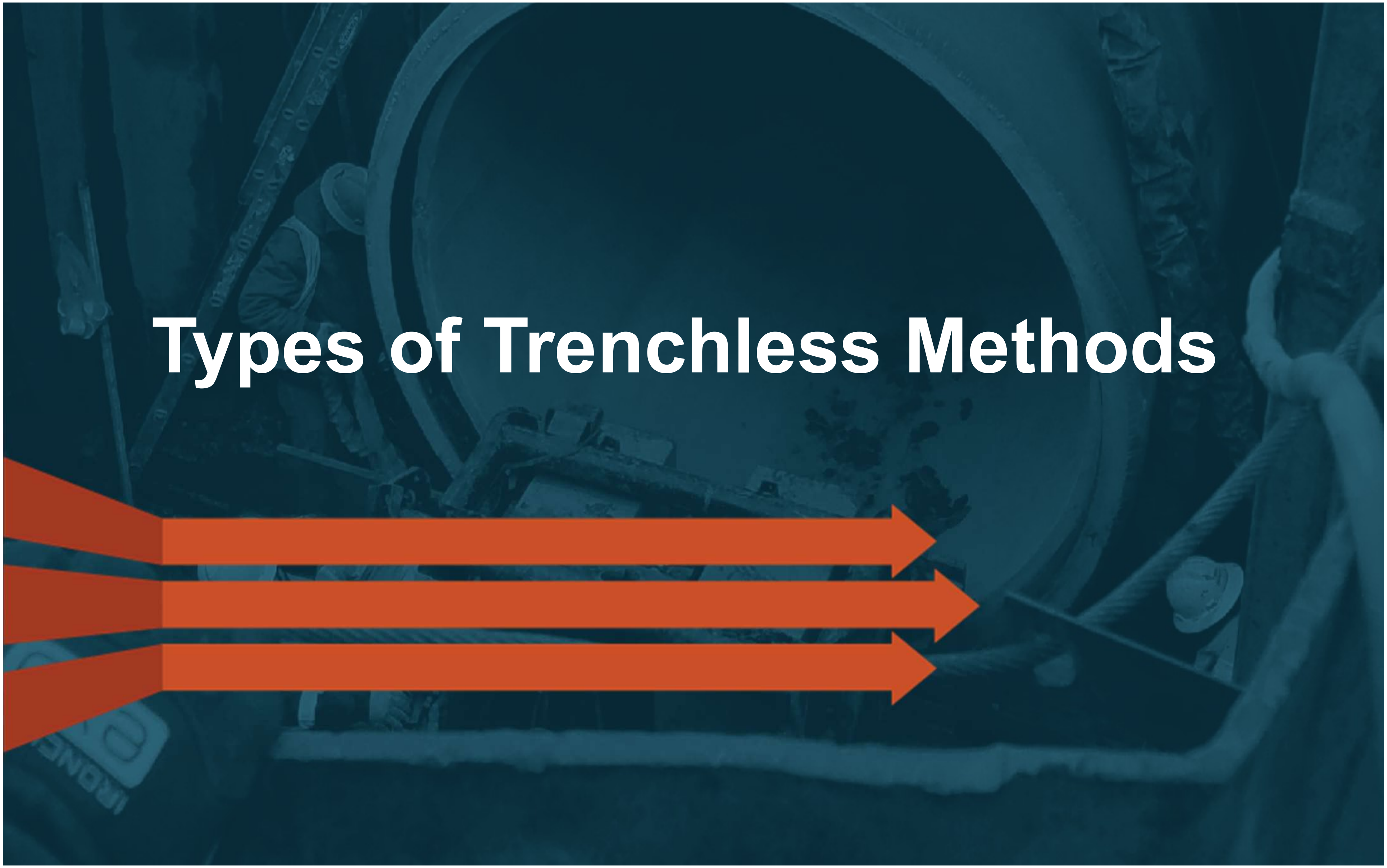
Hazen

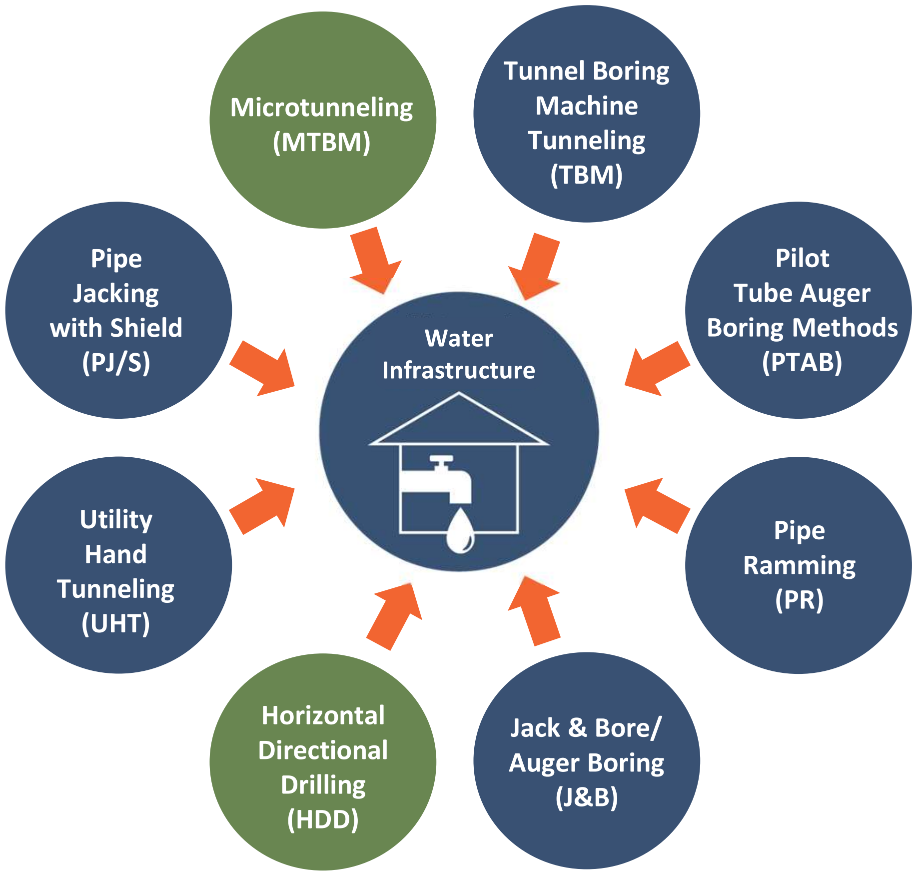
Webinar for Conveyance Design Professionals

HDD & Microtunneling Case Study

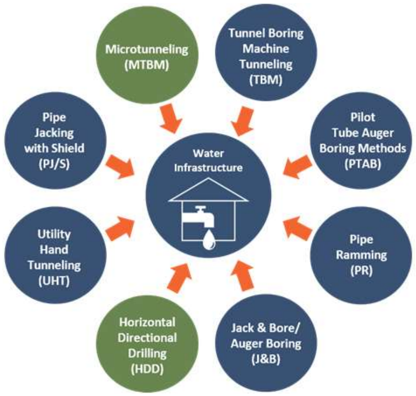
Upfront Planning Leads to Better Outcomes


Types of Trenchless Methods

Why Different Types of Trenchless Methods?



Why Different Types of Trenchless Methods?



Diameter

Drive Length

Line & Grade Accuracy

Ground Conditions
- Stability
- Excavatibility

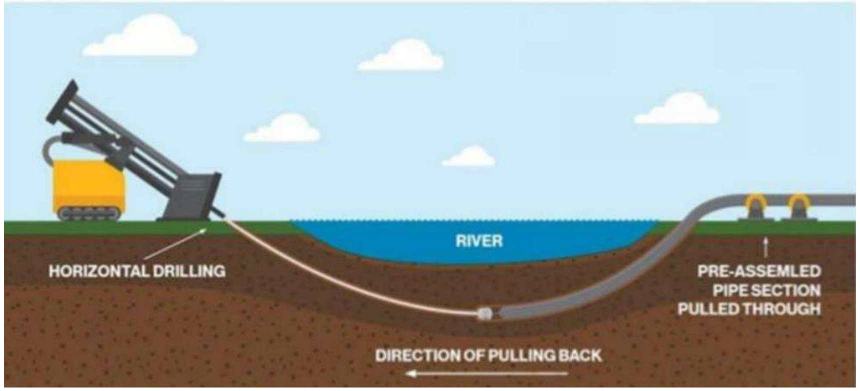
Space Constraints
- Cover/Clearance
- Setback/Laydown
- Site Footprint

Asset Life Cycle/Durability

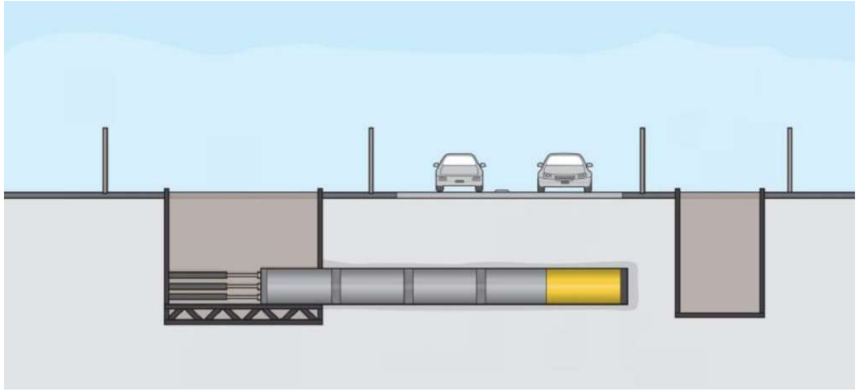
Environmental Sensitivity

Stakeholder Expectations

Types of Methods – Space Constraints

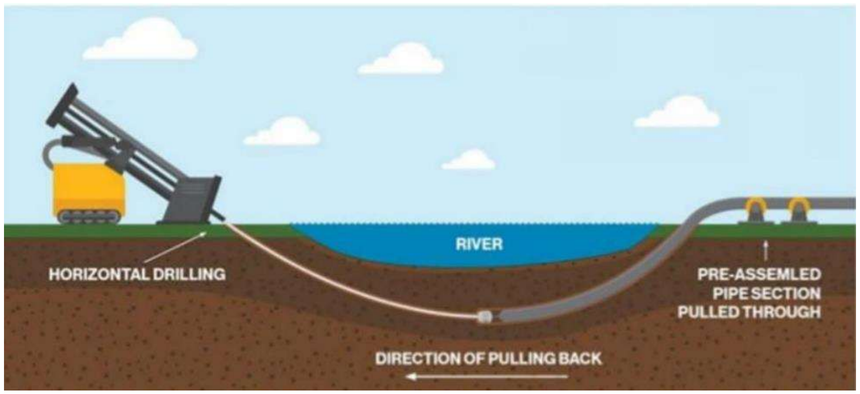


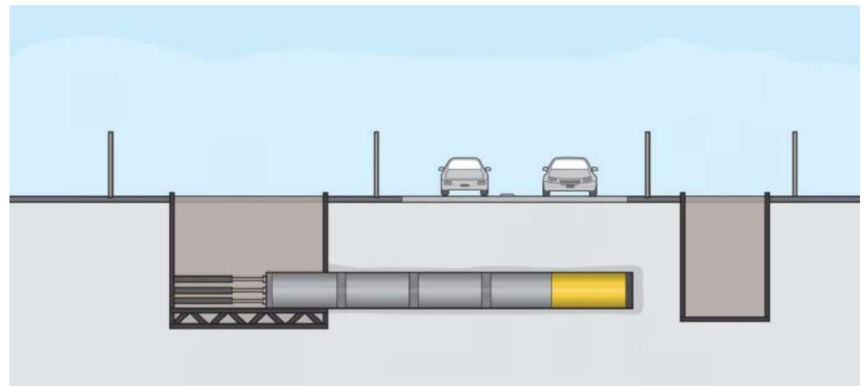
Surface Launched



Pit to Pit

Types of Methods – Space Constraints





Surface Launched

<u>Benefit</u>
No Shafts = Shorter Schedule & Lower Cost per foot

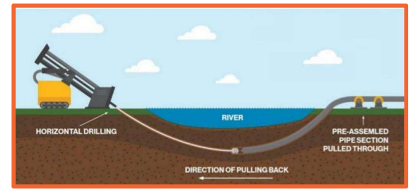
<u>Disadvantage</u>
Setback Required = Longer Length

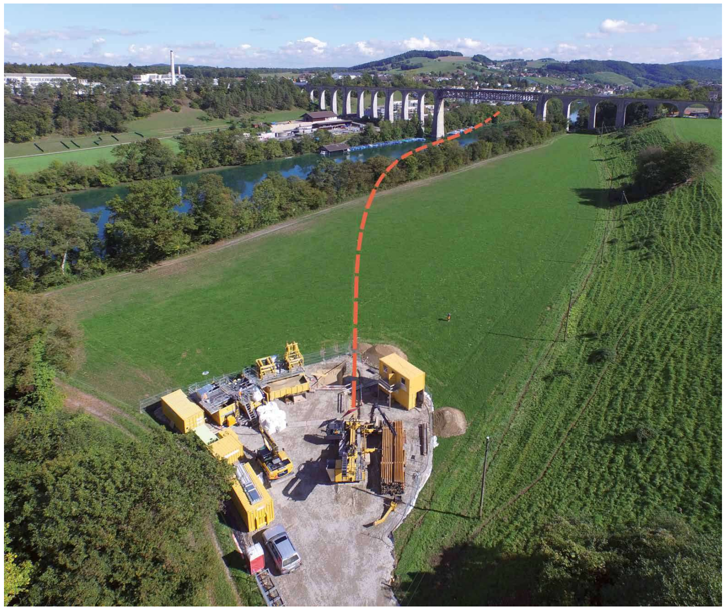
Pit to Pit

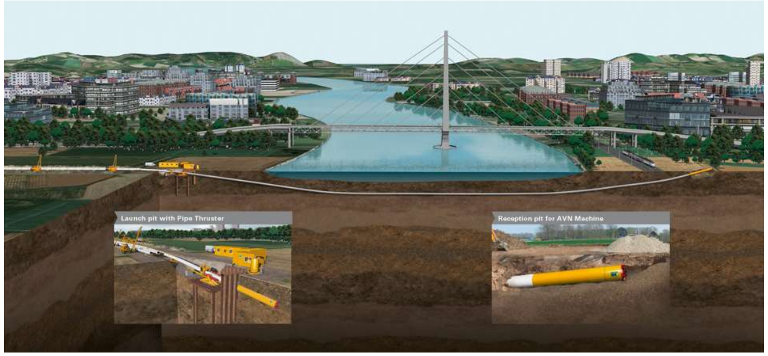
<u>Benefit</u>
No Setbacks = Shorter Drive Length & Less Property Required

<u>Disadvantage</u>
Shafts/Pits = Higher Cost & Longer Schedule

Surface Launched Technologies



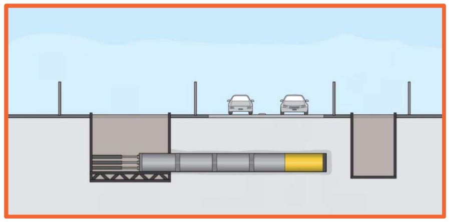




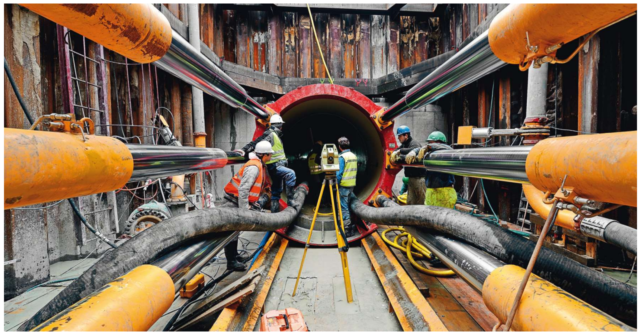
Horizontal Directional Drilling (HDD)

Direct Pipe (DP)

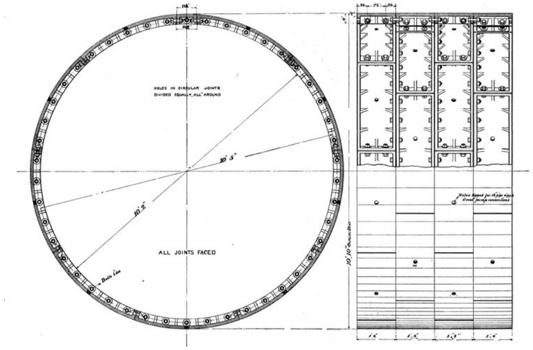
Pit to Pit Technologies



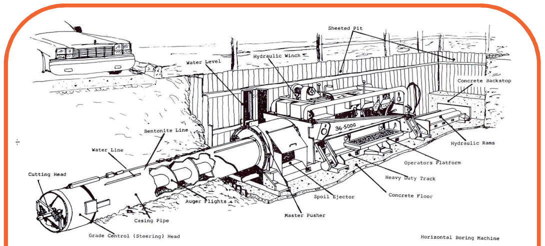
Pipe Jacking



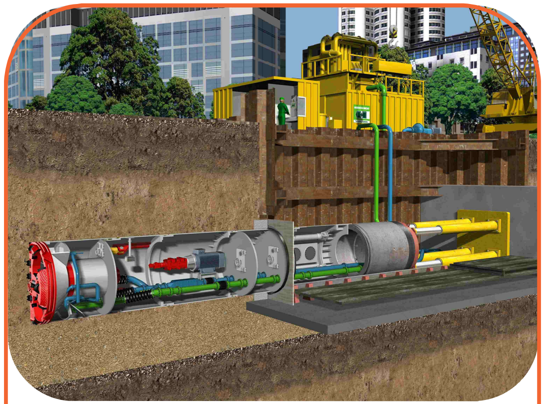
Segmental



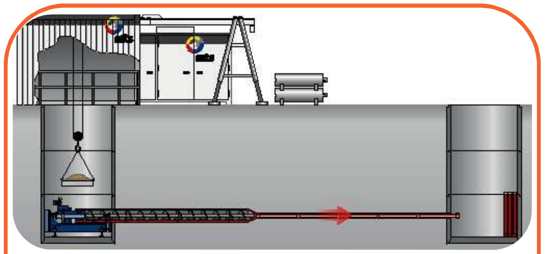
Pipe Jacking Methods



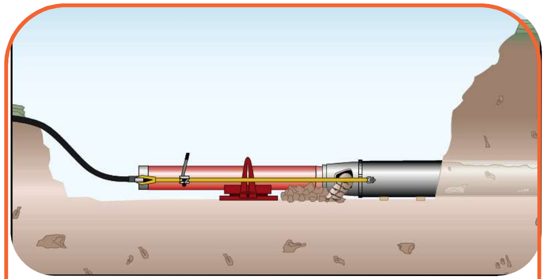
Horizontal Auger Boring
“Jack and Bore”



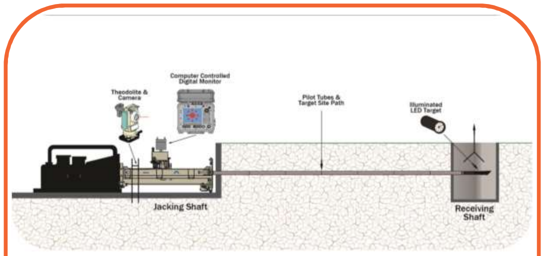
Microtunneling



Pilot Tube/Guided Auger Boring Methods



Pipe Ramming



Guided Jack and Bore

Segmental Methods

Tunnel Boring Machine (TBM)

Utility Hand Tunneling

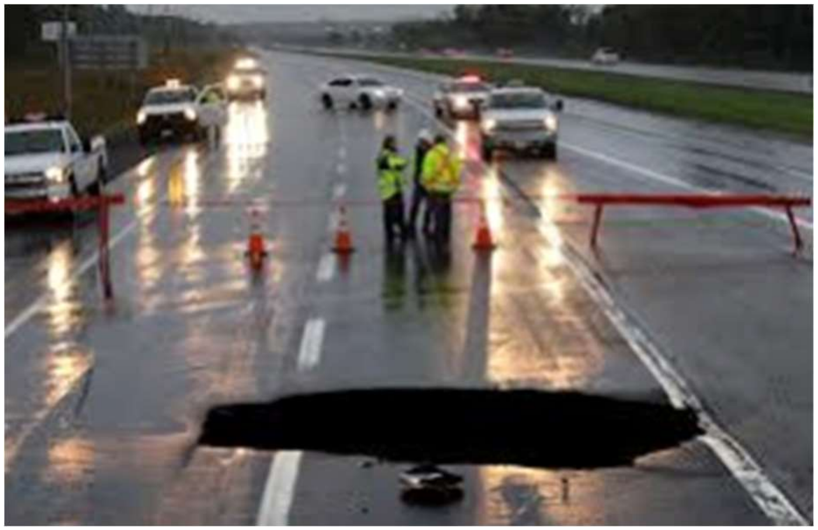
Drill & Blast and Soft Ground Hand Mining

Ground Conditions

Why Are Ground Conditions Important?

Settlement, Heaving, & Structural Damage

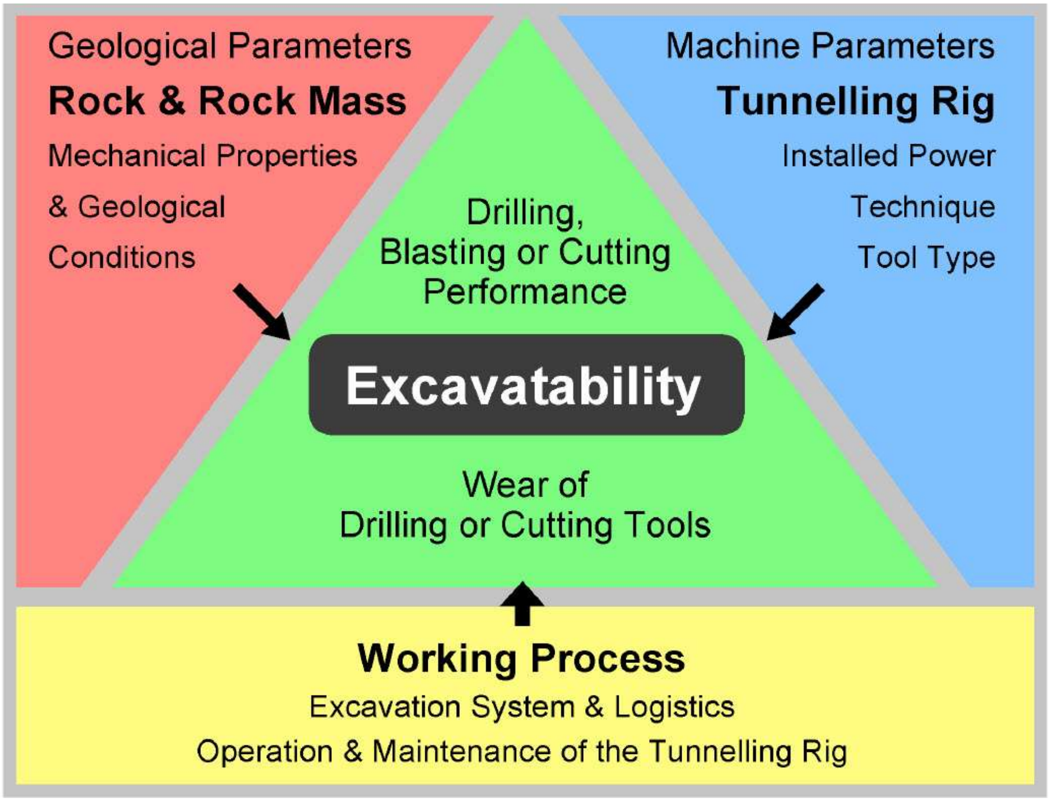
Immediate



Delayed

Excavatibility

Ground Conditions



Mixed Conditions

COBBLES

Size: 3" – 12" (typical)

BOULDERS

Size: Greater than 12"

Ground Conditions – Stability

FIRM
Example: hard, lean clay

SWELLING

Example: plastic clay

SQUEEZING

Example: soft to medium clay (under load)

Lower Risk — **Cohesive Soils** — **Higher Risk** →

RAVELING

Example: moist, dense sand

RUNNING

Example: dry sand

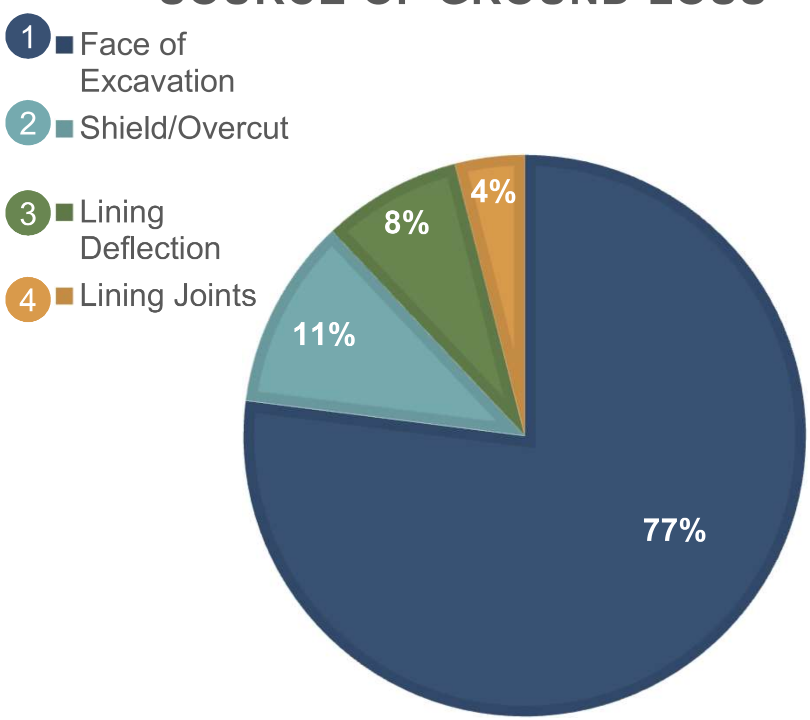
FLOWING

Example: saturated sand

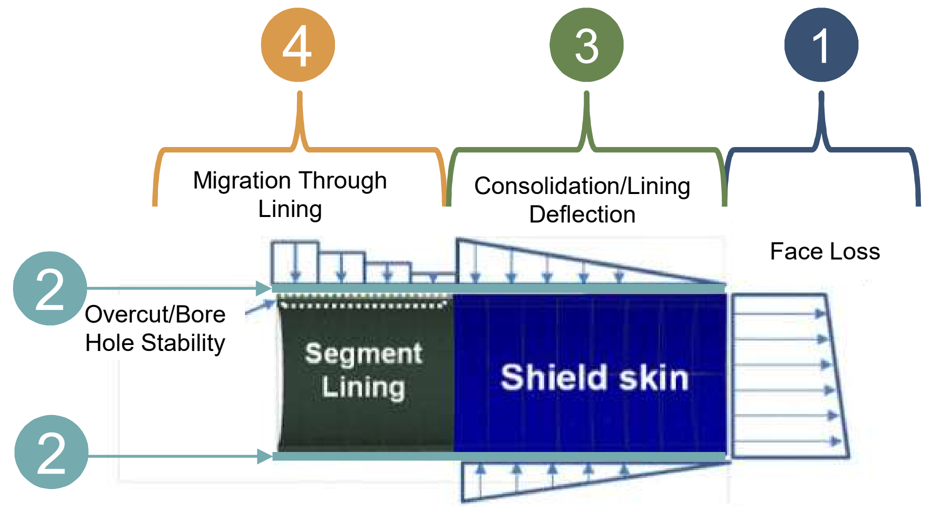
Lower Risk — **Non-Cohesive Soils** — **Higher Risk** →

Surface Settlement Risk

SOURCE OF GROUND LOSS



Ground Loss = Surface Settlement



Open Face Technologies

Excavation

Open Face TBM

Auger Boring

Jack and Bore & Pilot Tube

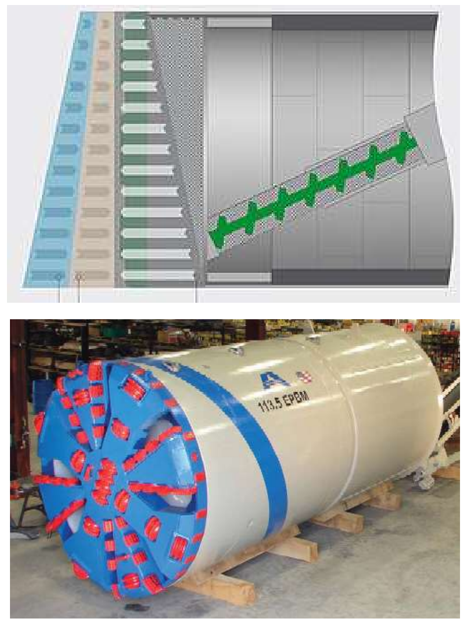
Utility Hand Tunneling

Pipe Jacking with Shield & Hand Mining

Closed Face Technologies

Excavation

Microtunneling



Closed Face TBMs

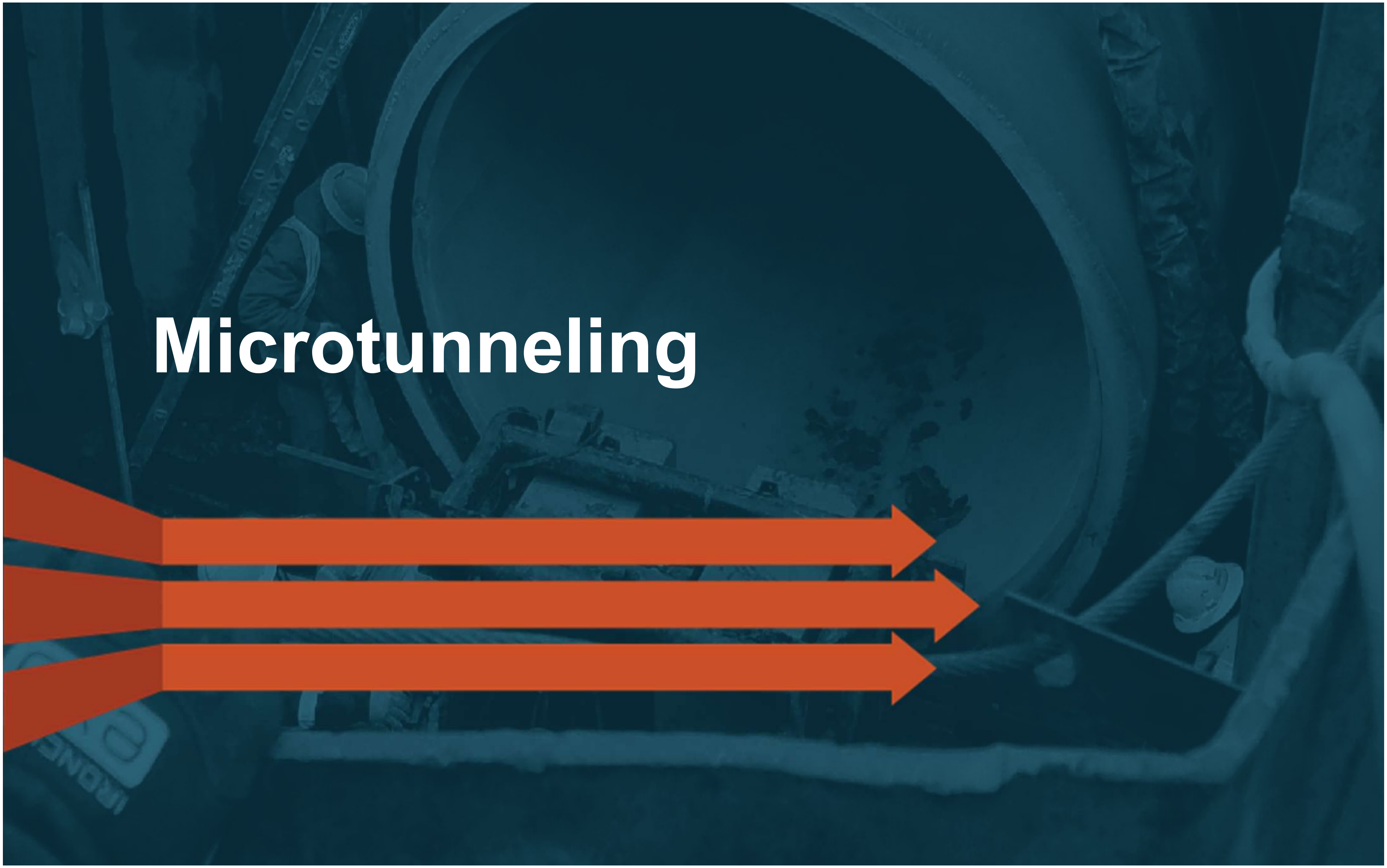
EPBM & Slurry Shield

HDD

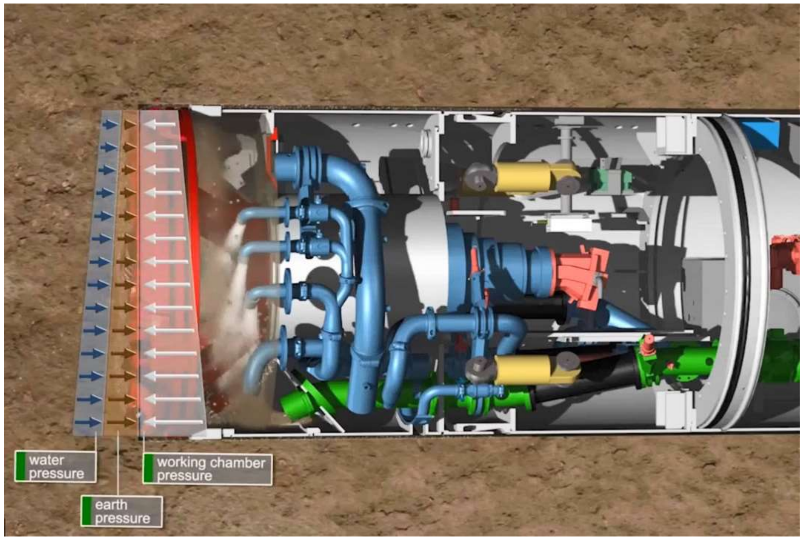
Trenchless Methods & Capabilities

	Ground Conditions/Behavior						
	Firm	Raveling	Running	Flowing	Cobbles	Hard Rock	Boulders
Open Face TBM							
Horizontal Auger Boring (Jack & Bore)							
Pilot Tube Auger Boring							
Utility Hand Tunneling							
Microtunneling							
EPBM/Slurry TBM							
HDD							
Pipe Ramming							

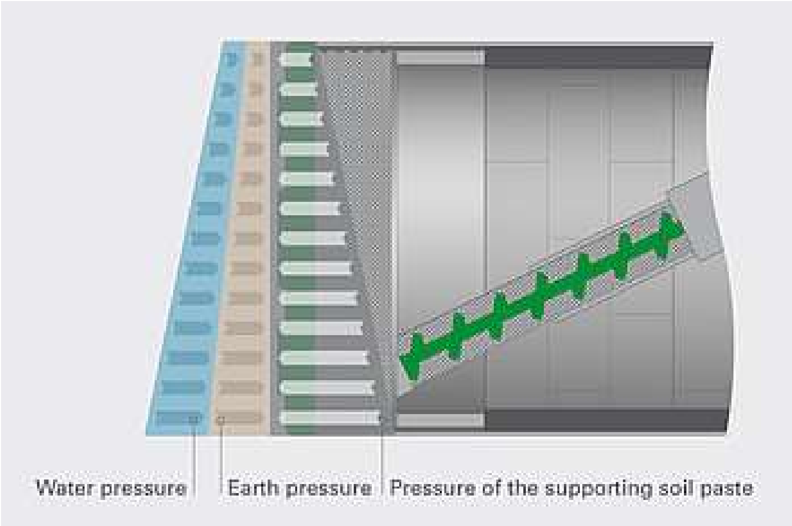
Microtunneling



Microtunneling - Closed Face Method



Slurry Supported Face

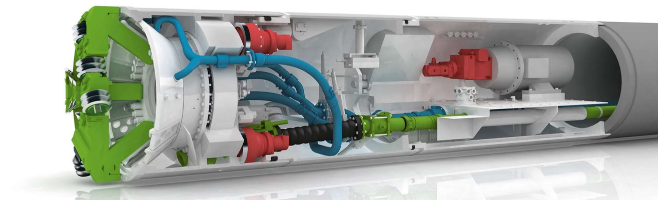


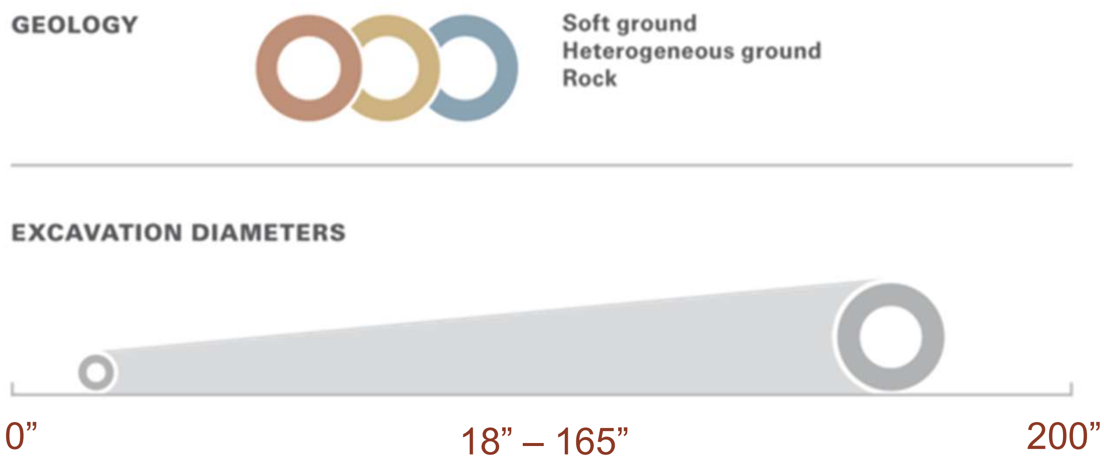
Earth Pressure Balance

Remote Control – *No Worker Entry Required*

Microtunneling

Operator's Unit





MTBM -
Slurry Microtunneling

Size

- *“Micro” = Misnomer*
- 18” - 165” Diameter

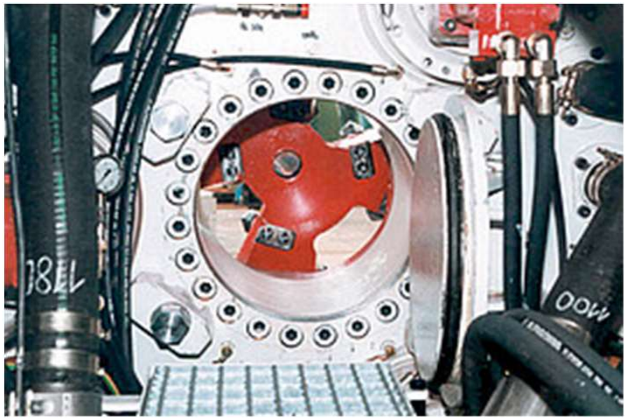
Capability

- Soft Ground
- High Groundwater Pressure
- Mixed Ground
- Rock

Rock Microtunneling requires > 60” Diameter

Slurry MTBM with Rock Cutter Head

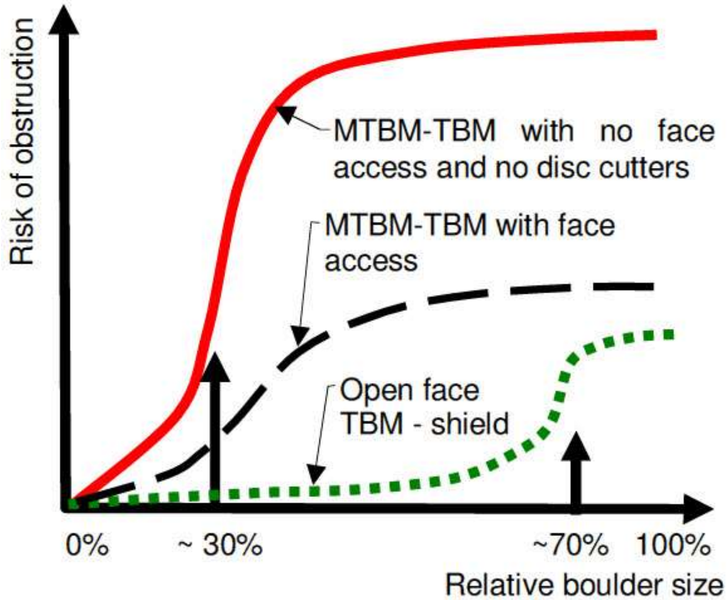
Slurry MTBM with Mixed Face Cutter Head



Access Door for Worn Cutter Replacement

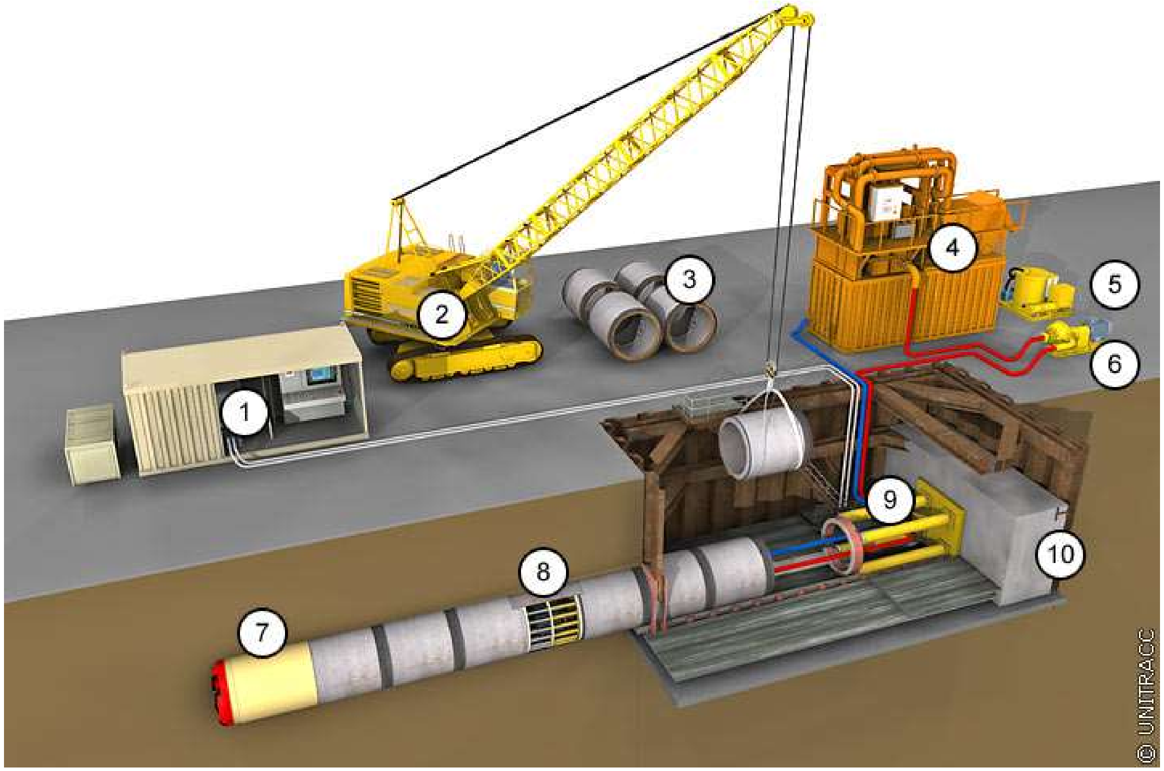
Obstructions

Obstructions



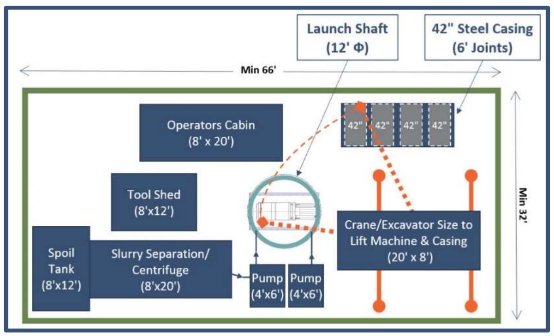
Typical Launch Site

Microtunneling



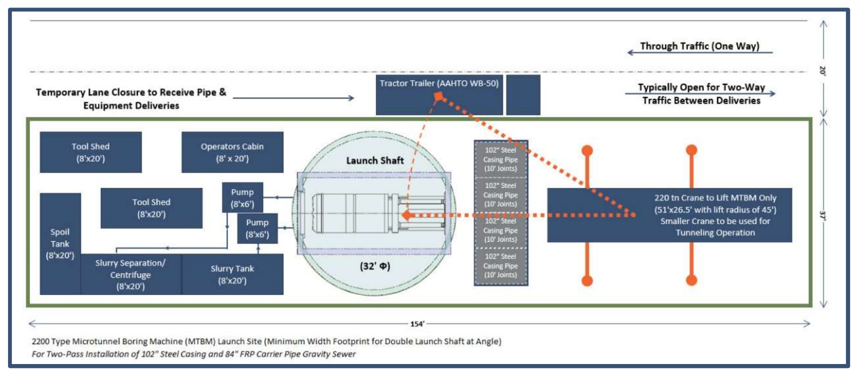
1. Operator
2. Crane
3. Jacking Pipe/Casing
4. Slurry Separation Plant
5. Generator
6. Slurry/Spoil Pumps
7. MTBM
8. Intermediate Jacking Station
9. Jacking Frame
10. Reaction/Thrust Wall

Microtunneling – Launch Shaft Site Varies by Equipment Size



42" Two-Pass MTBM Installation
66' x 32'

102" Two-Pass MTBM Installation
154' x 37'



Launch Shaft Footprints Can Vary Significantly

Fisher Island Launch Shaft
(Contractor used all area available)

Miami Beach Launch Shaft
(site is significantly constrained)

72" Microtunnel Crossings, Port of Miami Utility Relocation Project

Microtunneling Launch Shaft Footprint

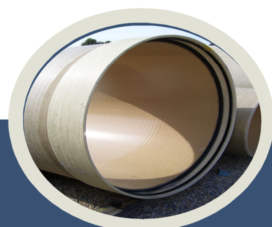
Two-Pass vs Single-Pass

Single Pass

Two-Pass

Jacking Pipe/Casing Materials

Reinforced Concrete[1]	RCP (ASTM C76)	18" – 96" ID (in US) up to 136" (in Europe)
Fiberglass Reinforced[1]	FRP (ASTM D3754)	24" – 120" ND
Carbon Steel	CS (ASTM A139)	Butt Welded or Permalok,
Vitrified Clay Pipe	VCP (ASTM C-1208)	8" – 48" (Improved Joint)
Polymer Mortar Pipe	PMP (ASTM C76)	Double Spigot w/ SST Comp Coupling - ASTM and sizes same as RCP



[1] Hybrids such as fiberglass lined, reinforced concrete jacking pipe are now being introduced

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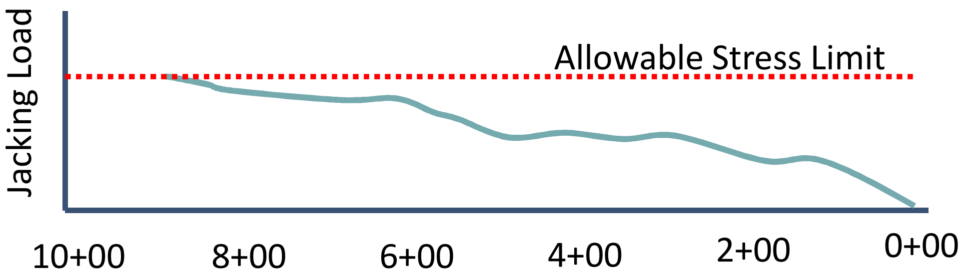
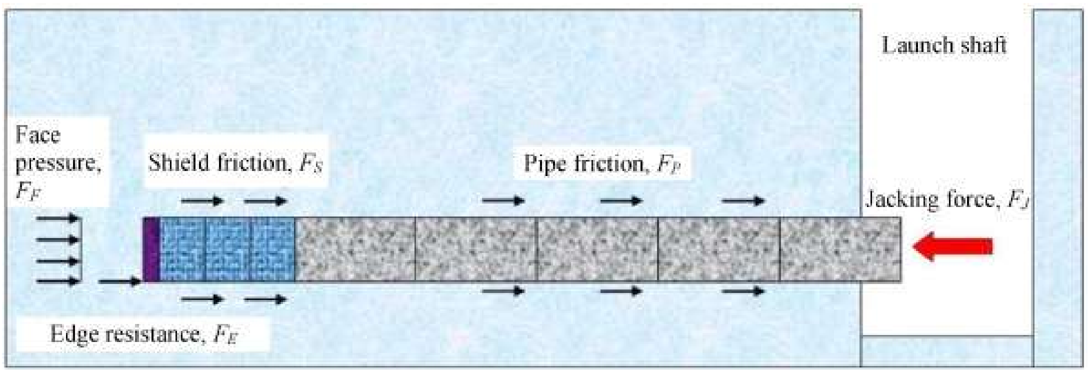
Pipe Jacking Technology

Microtunneling





Jacking Force Required
(Frictional Resistance Buildup)

VS

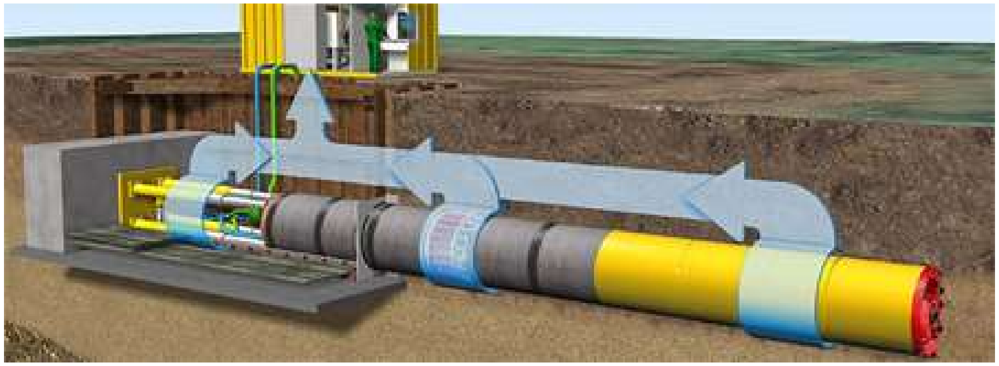
Jacking Pipe
(Allowable Yield Strength)

Pipe Jacking Technology

Microtunneling

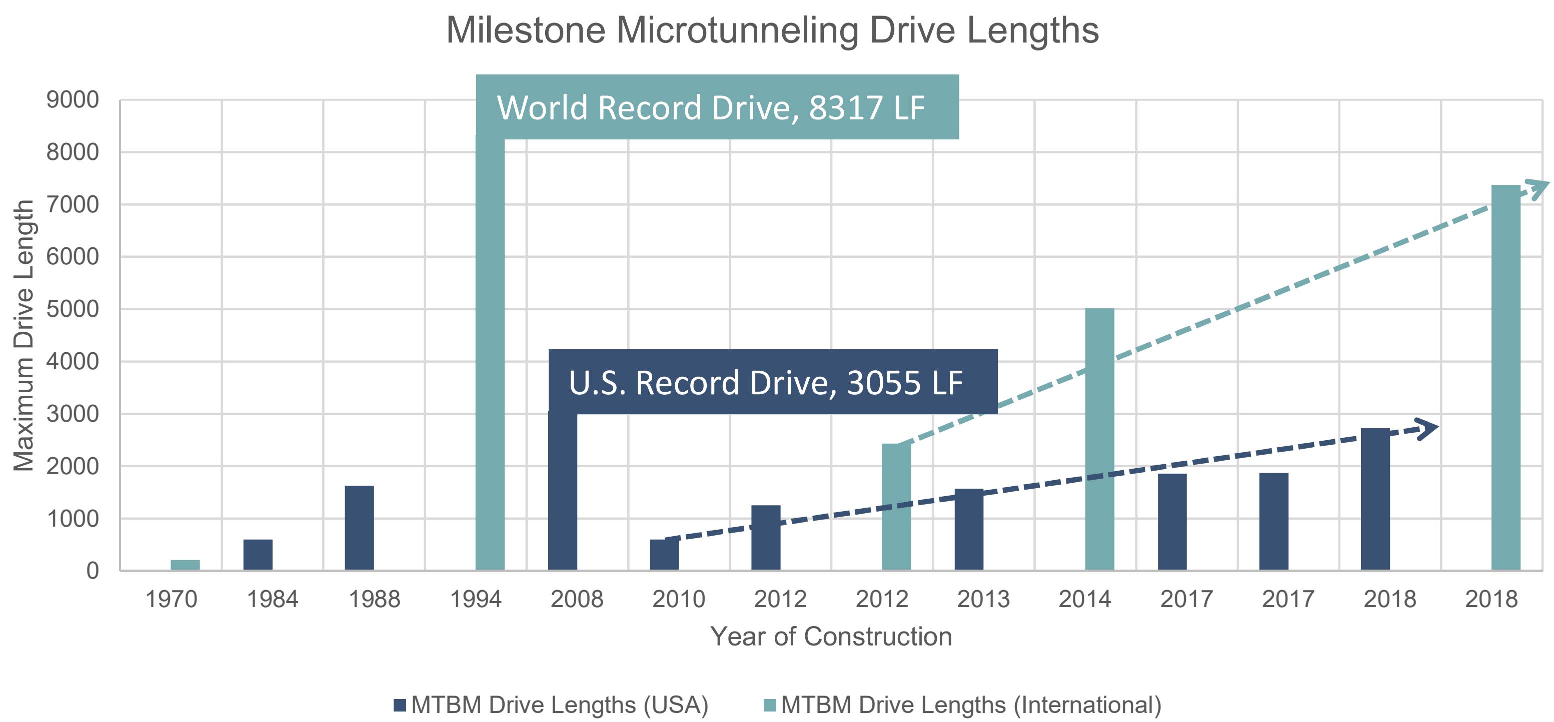
<u>Mitigation Strategies</u>

- Lubrication
- Intermediate Jacking Stations



Maximum Drive Lengths

Microtunneling



Factors Affecting Costs

Microtunneling

Pipe

- Pipe Material – RCP, FRP, Steel, VCP
- Welding vs Interlocking Joint
- Two-Pass vs Single Pipe

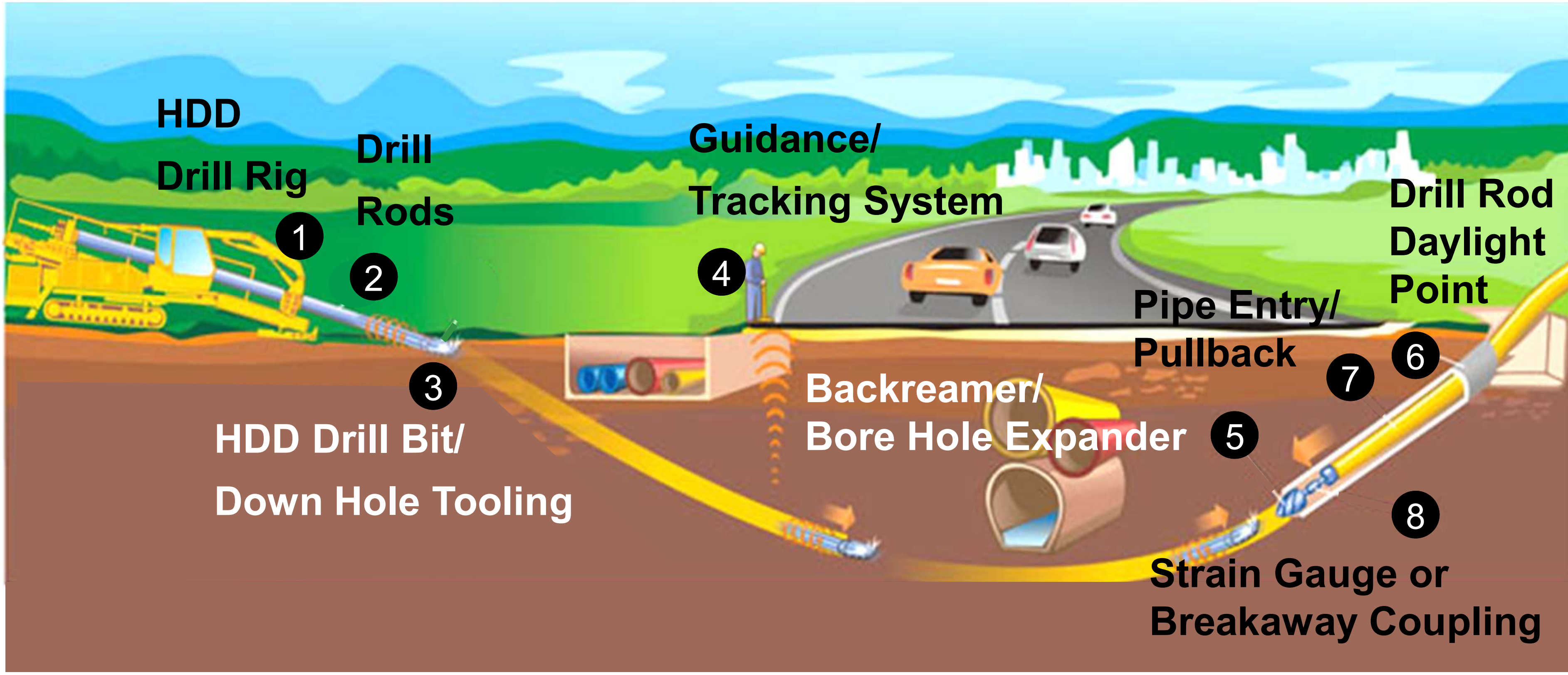
Rock, Mixed Ground, Poor Strength Soils

Risk

Average Costs

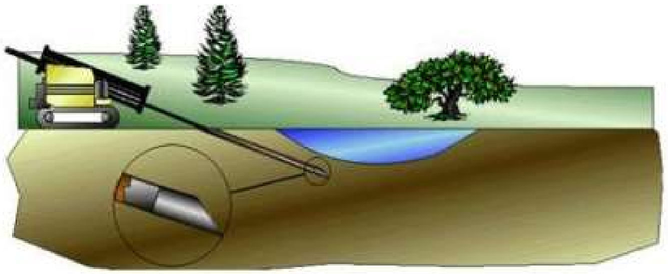
- $55 to $95 per foot per inch diameter
- Shaft SOE type, depth, vf vs drive length (significant cost factor)

Horizontal Directional Drilling

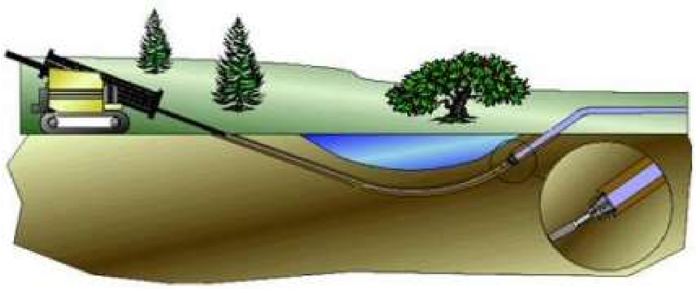

HDD
Drill Rig
1
Drill
Rods
2
Guidance/
Tracking System
4
Drill Rod
Daylight
Point
Pipe Entry/
Pullback
6
7
3
Backreamer/
Bore Hole Expander
5
HDD Drill Bit/
Down Hole Tooling
8
Strain Gauge or
Breakaway Coupling

What is HDD?

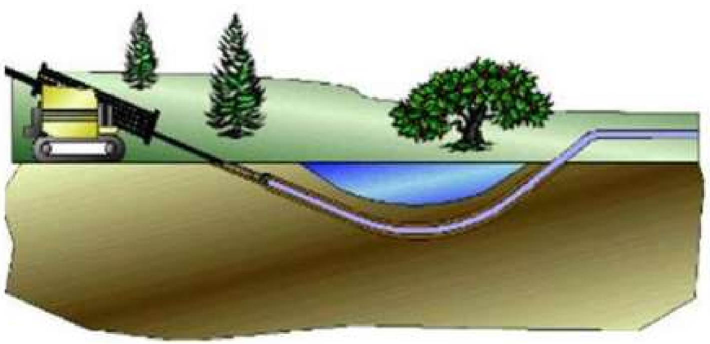
HDD Phases



1. Drill Pilot Hole



2. Expand Hole (Backreamer)



3. Pull Pipe (Pull Back)

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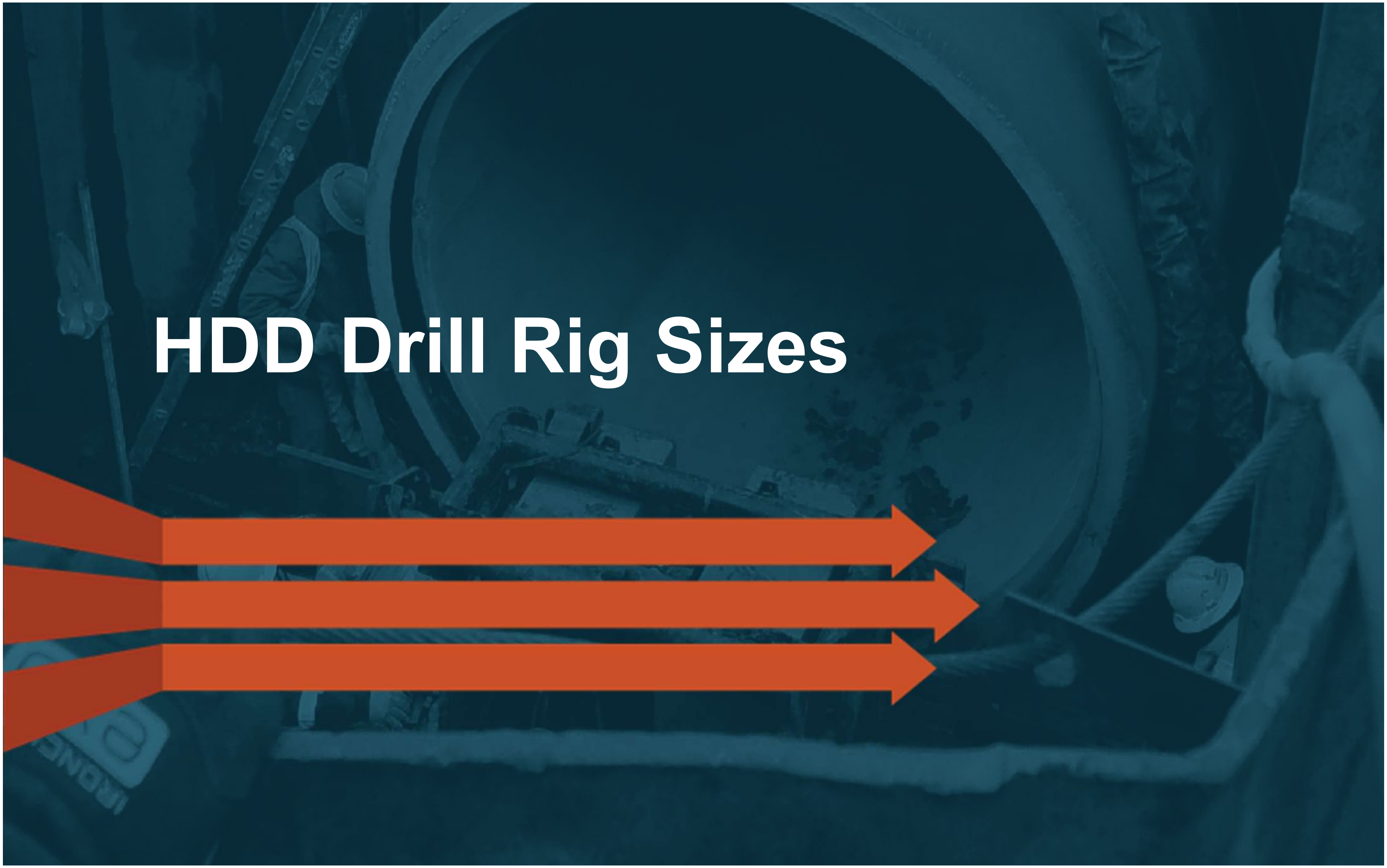


HDD Drill Rig Sizes

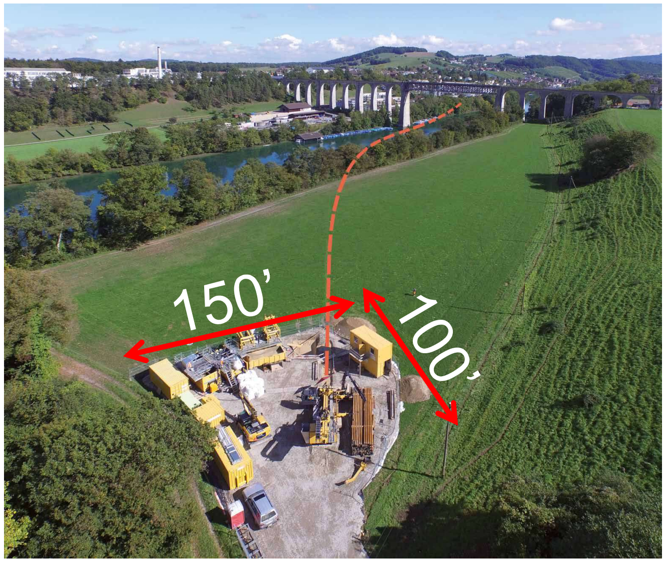
Proper Expectations for HDD Equipment Size

Compact HDD Drill Rig
150,000 lbs to 250,000 lbs Max Pullback

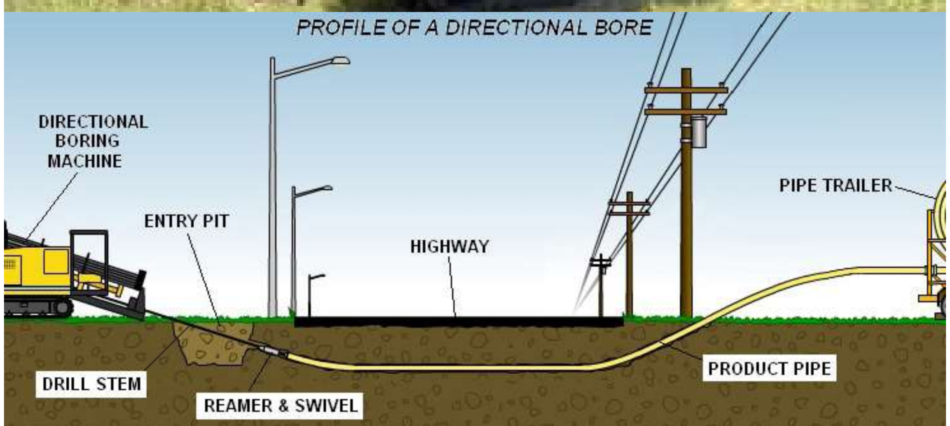
Large HDD Drill Rig
>1,000,000 lb Pullback Capacity

Proper Expectation for HDD Equipment Size

Compact HDD Drill Rig
150,000 lbs to 250,000 lbs Max Pullback



Large HDD Drill Rig
>1,000,000 lb Pullback Capacity



HDD Mini Rig

Pull Force:	up to 40,000 lbs
Torque:	up to 4,000 lbs
Pumping:	up to 75 gpm
Dia:	up to 6” (4” ID)
Length:	up to 600 ft

HDD Midi Rig

Pull Force:	40,000 - 200,000 lbs (+)
Torque:	>20,000 lbs
Pumping:	50-200 gpm
Dia:	up to ~16”
Length:	up to 2,000 ft

HDD Maxi Rig

Pull Force: >200,000 lbs

Torque: >20,000 lbs

Pumping: >200 gpm

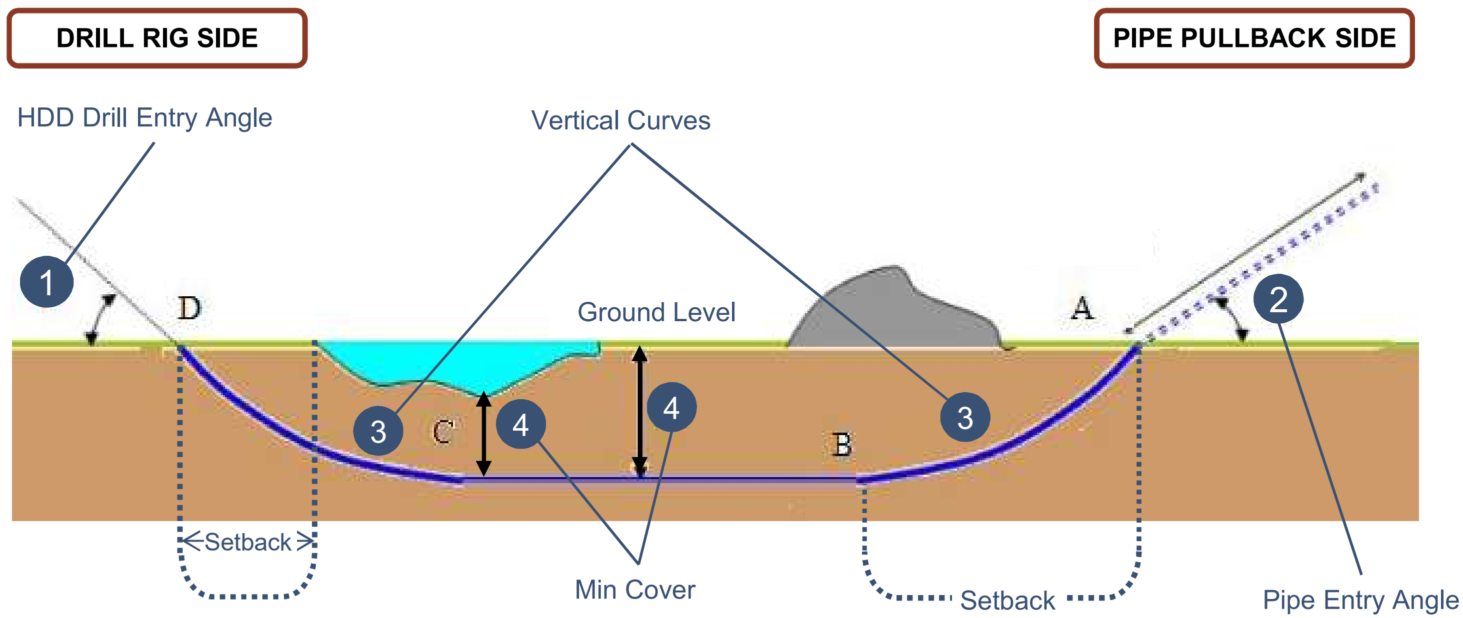
Dia: up to 54”

Length: 2,000 ft – 8,000 ft*

* >10,000 ft has been accomplished using a mid-path drill intercept (i.e. 2 opposing drill rigs)

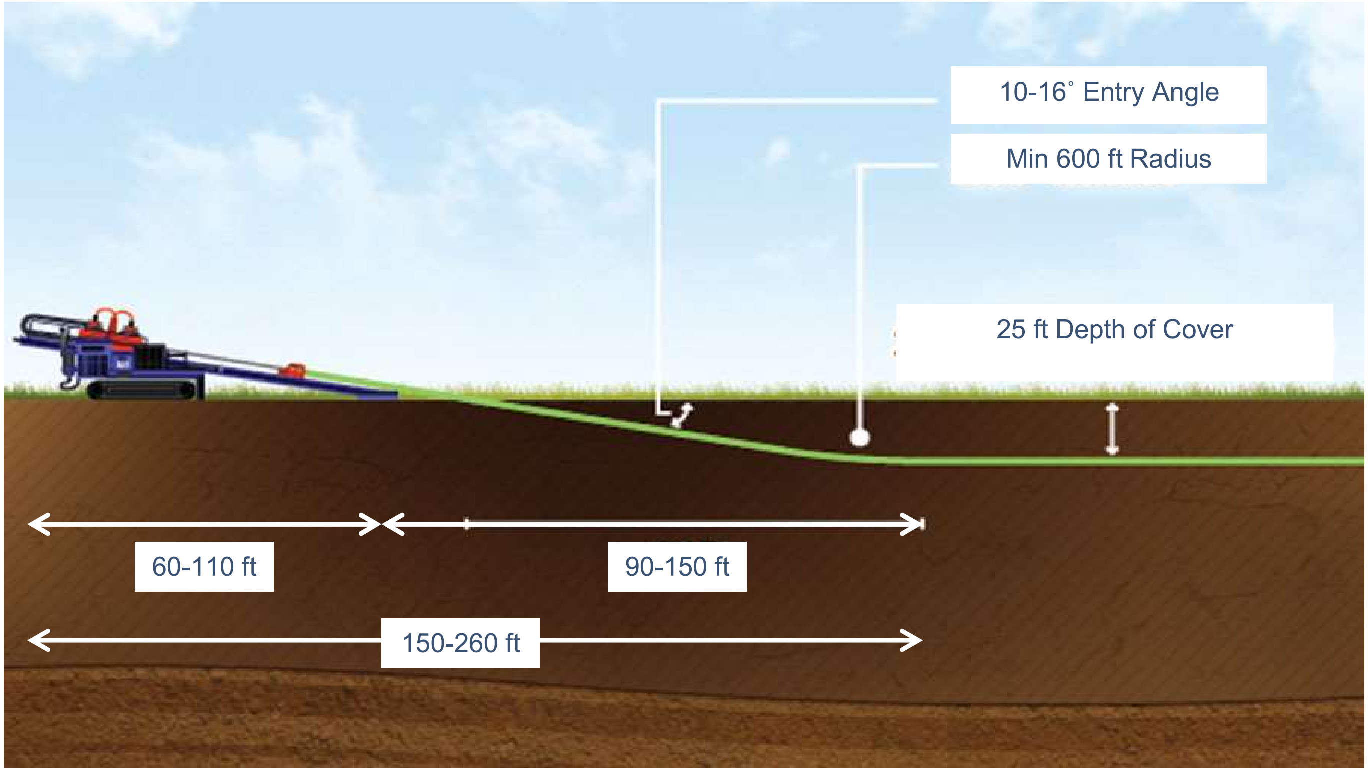
HDD Borepath Geometry

Constructability



Establishing a Borepath for Success

Setbacks and Depth



Allowable Bending Radius

Dependent on:

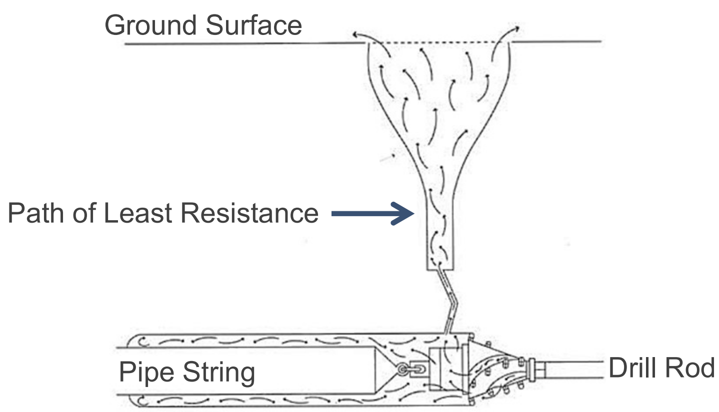
- Pipe Material
- Wall Thickness
- Combination of Installation Stresses

R_{allow} → Material Bending Stress + Axial Stress due to Tension + Critical Ring Buckling

Hydrofracture

Also known as…

- Inadvertent Drilling Fluid Returns
- Commonly referred to as a Frac-out



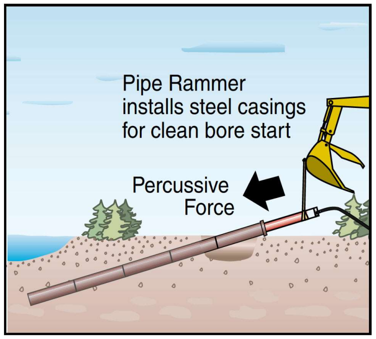
Hydrofracture Mitigation

Relief Wells

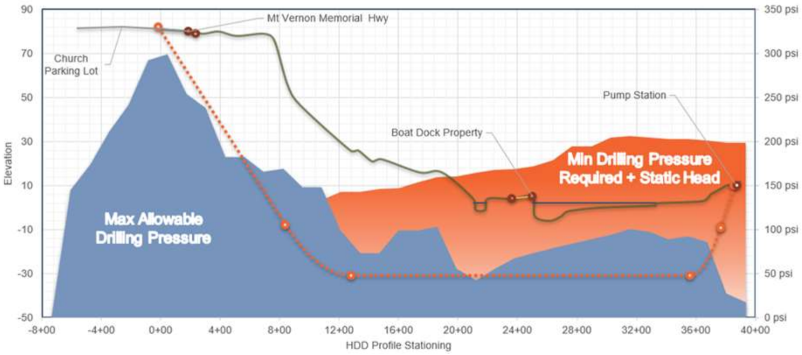
Inadvertent
Drilling Fluid
Returns

Contingency
Plan

Contingency Planning



Conductor Barrell



Modeling

Minimum Depth of Cover

Goal: Prevention of Surface Heaving & Frac-outs

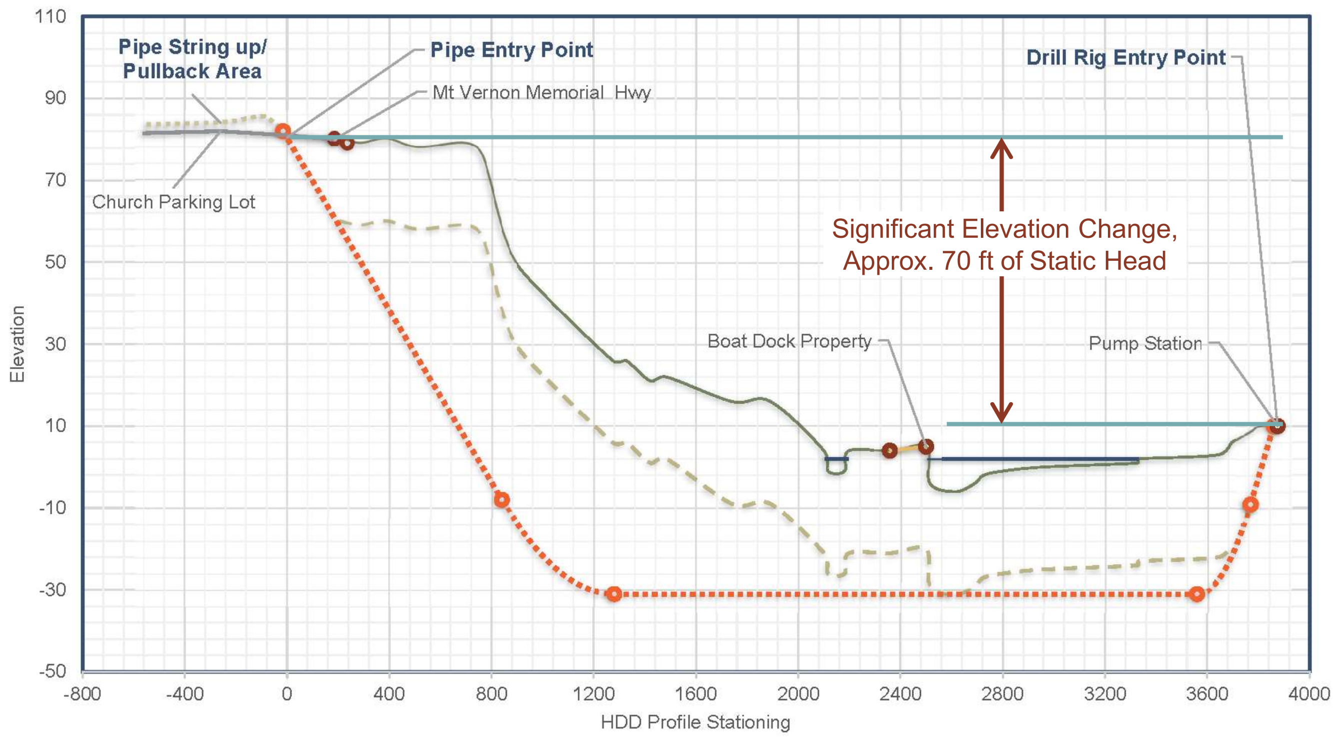
Min Cover (≤ 4" dia) = 3'

Min Cover (≥ 4" dia) = 5 * Borehole Diameter

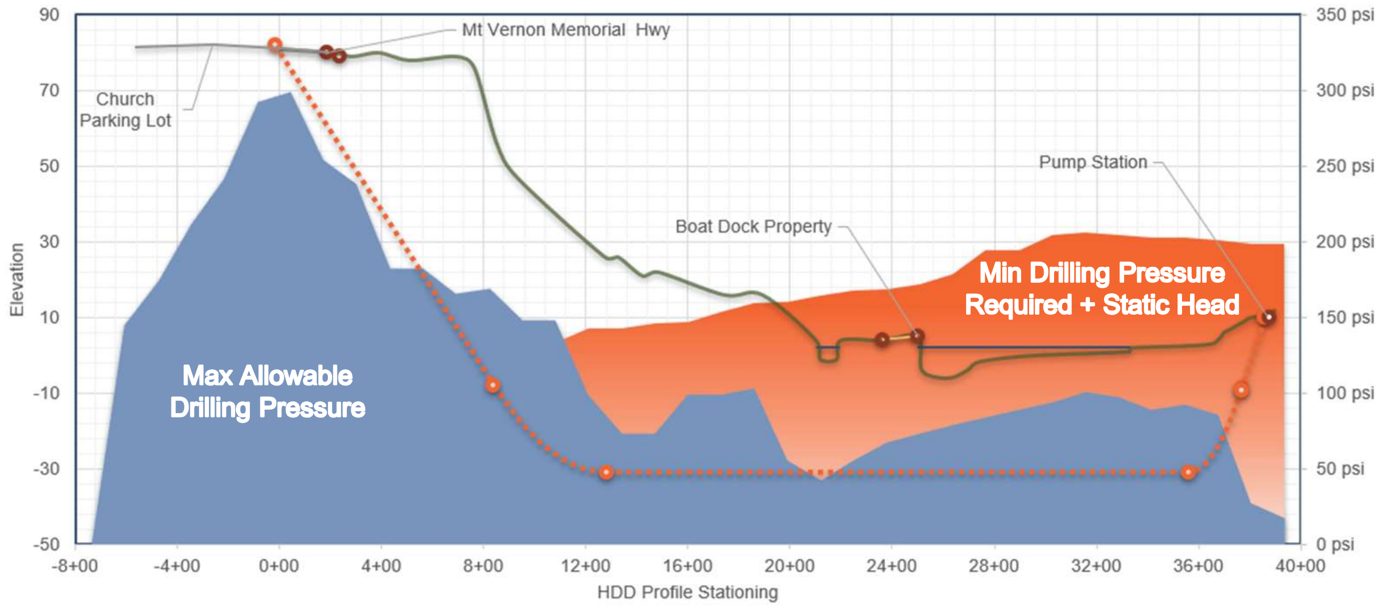
Borehole Diameter = 50% of Pipe OD

Example:
16" HDPE (DIPS, PE4710) OD = 17.40"
1.5 * 17.40" = 26.1" roundup for Backreamer Size → 28" (2.3')
5 * 28" = 140" (or 11.7')
Say ***Min Depth of Cover is 12' to Top of Borehole****, or*
Set invert *at 12' + Borehole Dia (2.3')* ***= 14.3'***

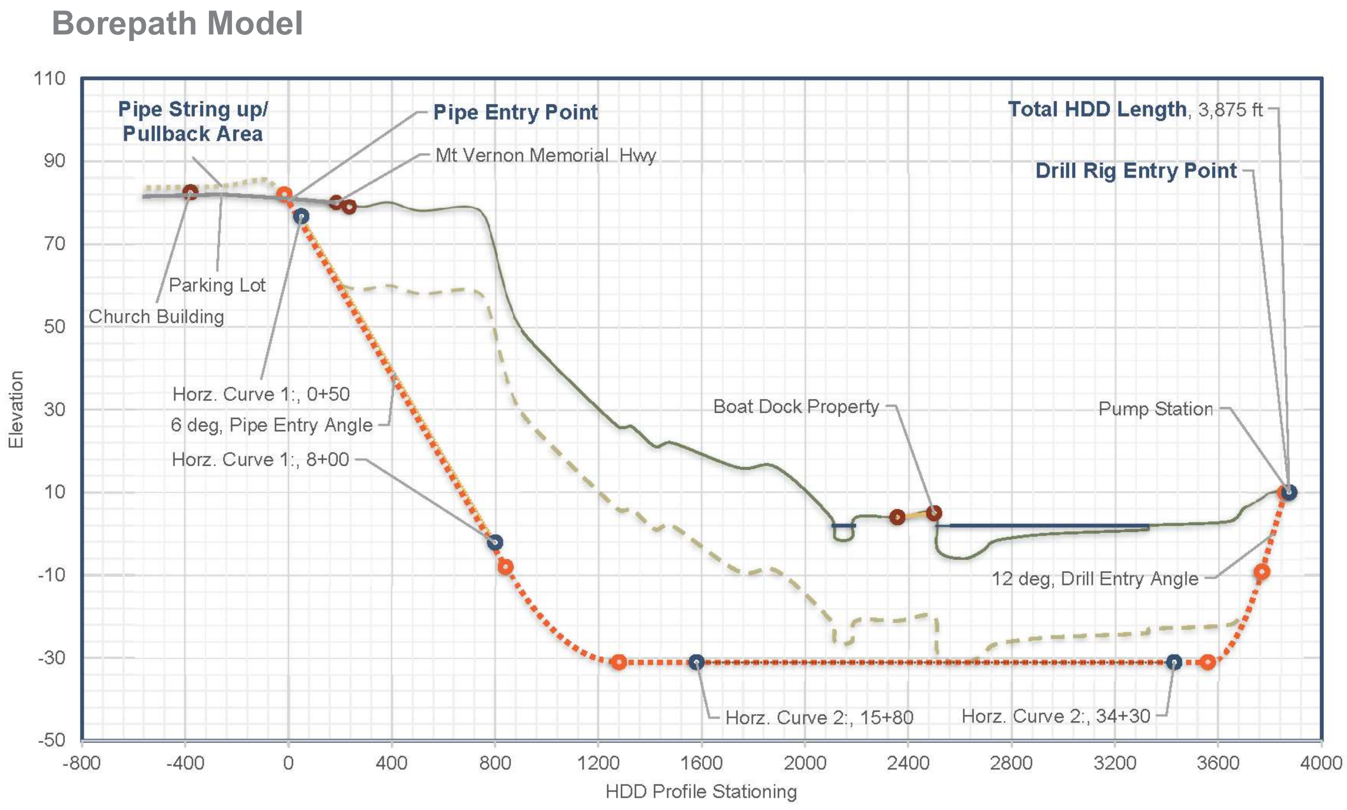
Addressing Large Elevation Changes



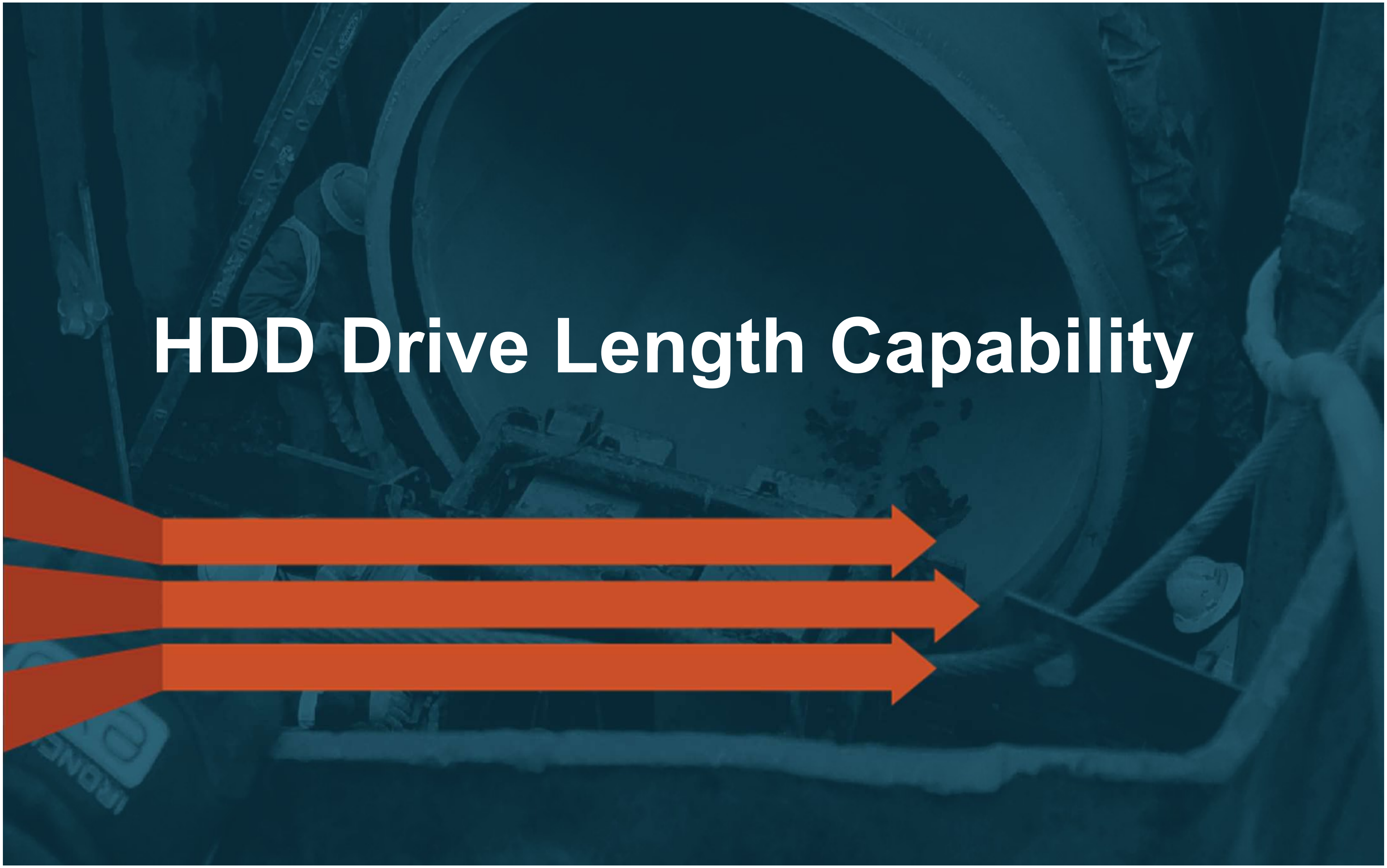
Addressing Large Elevation Changes

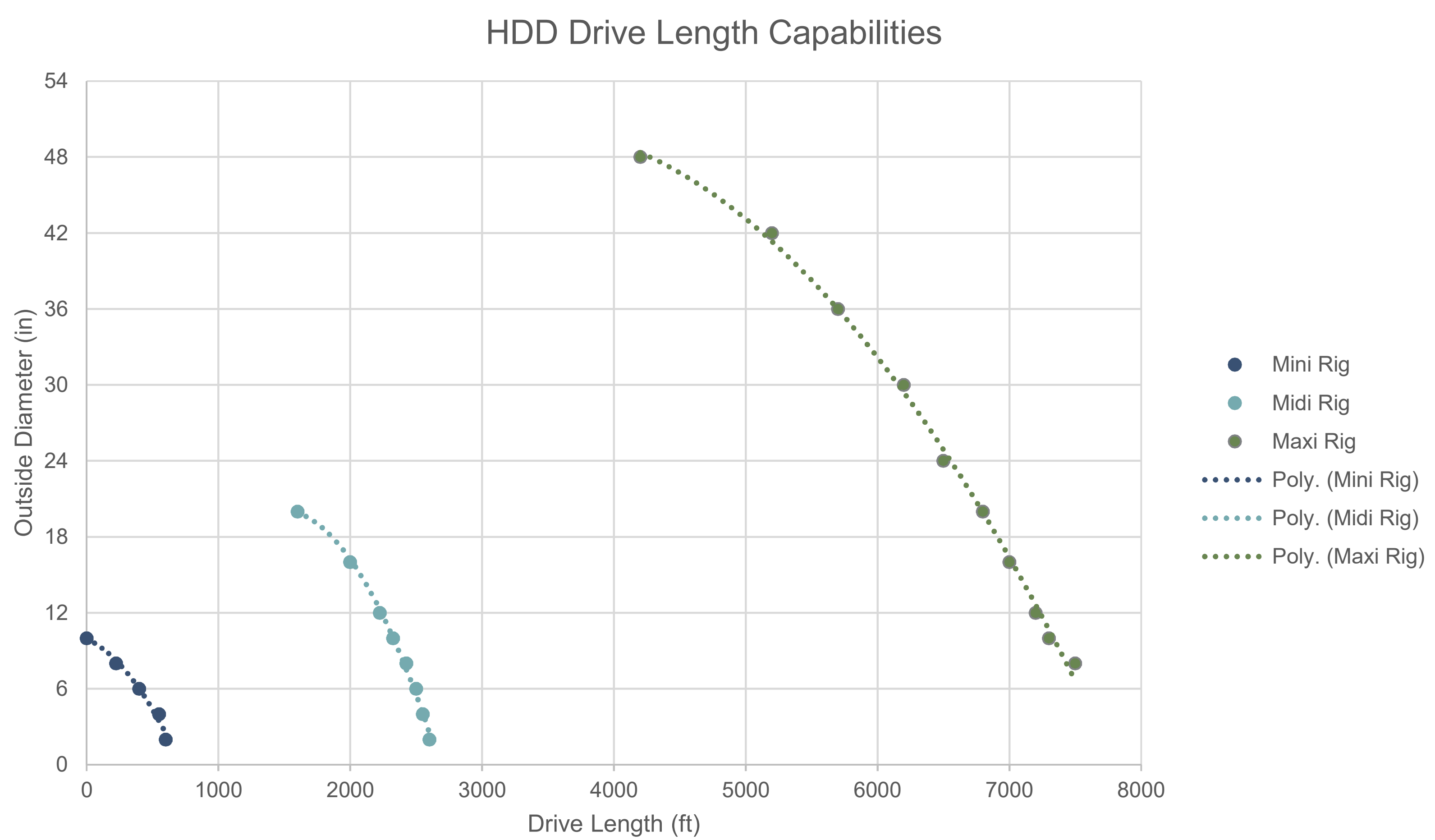


Identification of a Successful Borepath

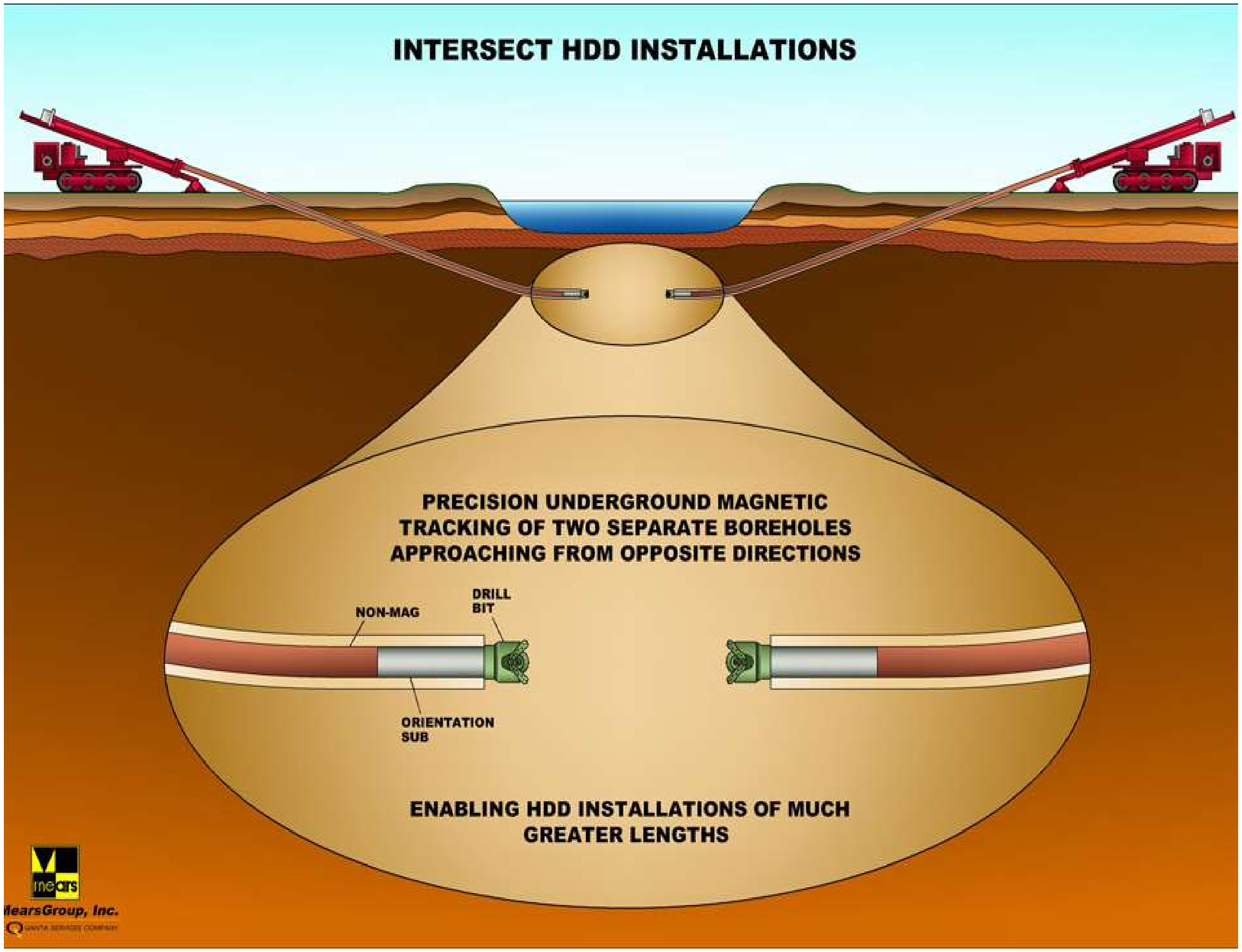


HDD Drive Length Capability





HDD Drive Length Capabilities – *some max lengths require steel pipe*



HDD Capabilities

<u>Max Length</u>

Intersect Method

> 10,000 ft

Pipe Materials

Most Widely Used

High Density Polyethylene (HDPE) Pipe – fused joints

Carbon Steel – welded joints

- ASTM A53, grade B
- API 5L, X-grades

Others

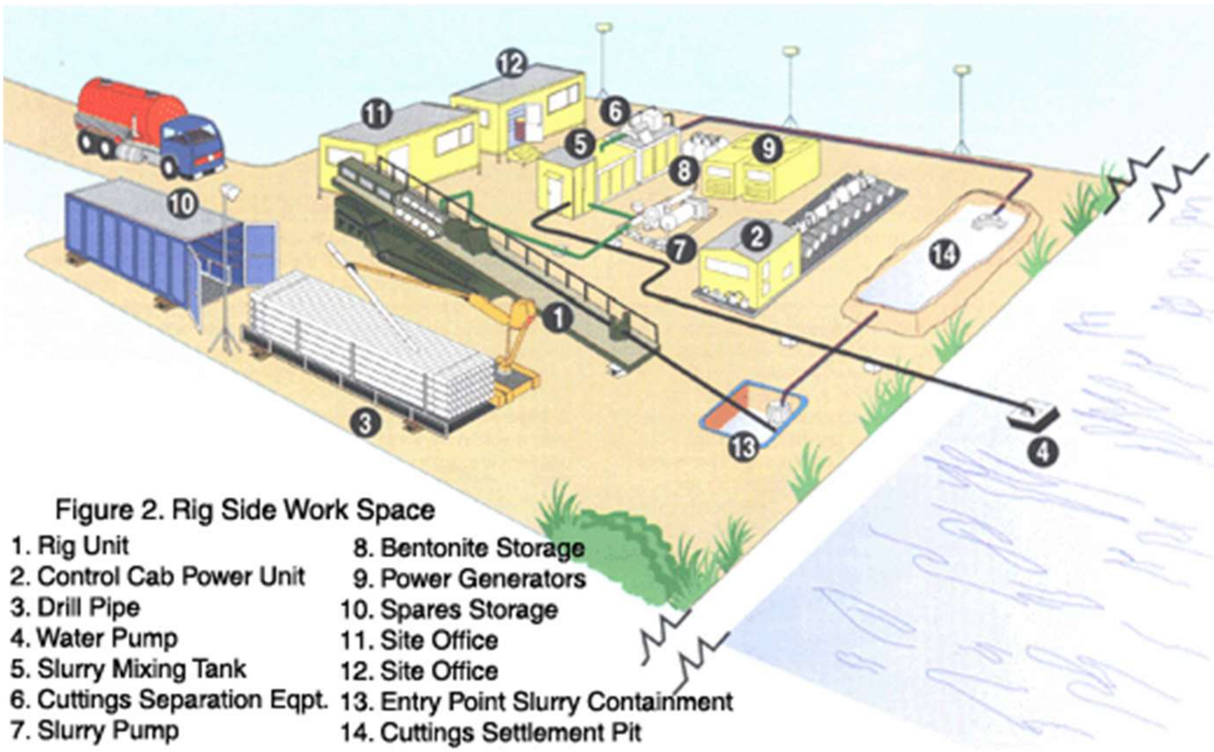
Fusible Polyvinyl Chloride (fPVC) Pipe – fused joints

Ductile Iron Pipe (DIP) – restrained joint

HDD Space Requirements

Maxi (Large) Drill Rig Site

HDD Footprint – Maxi (Large) Drill Rig Site

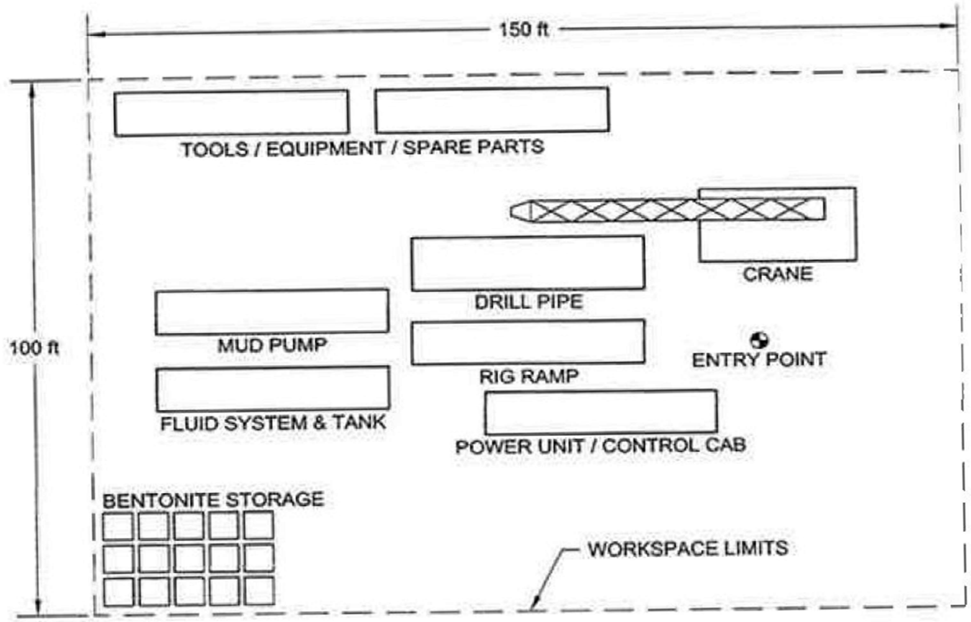


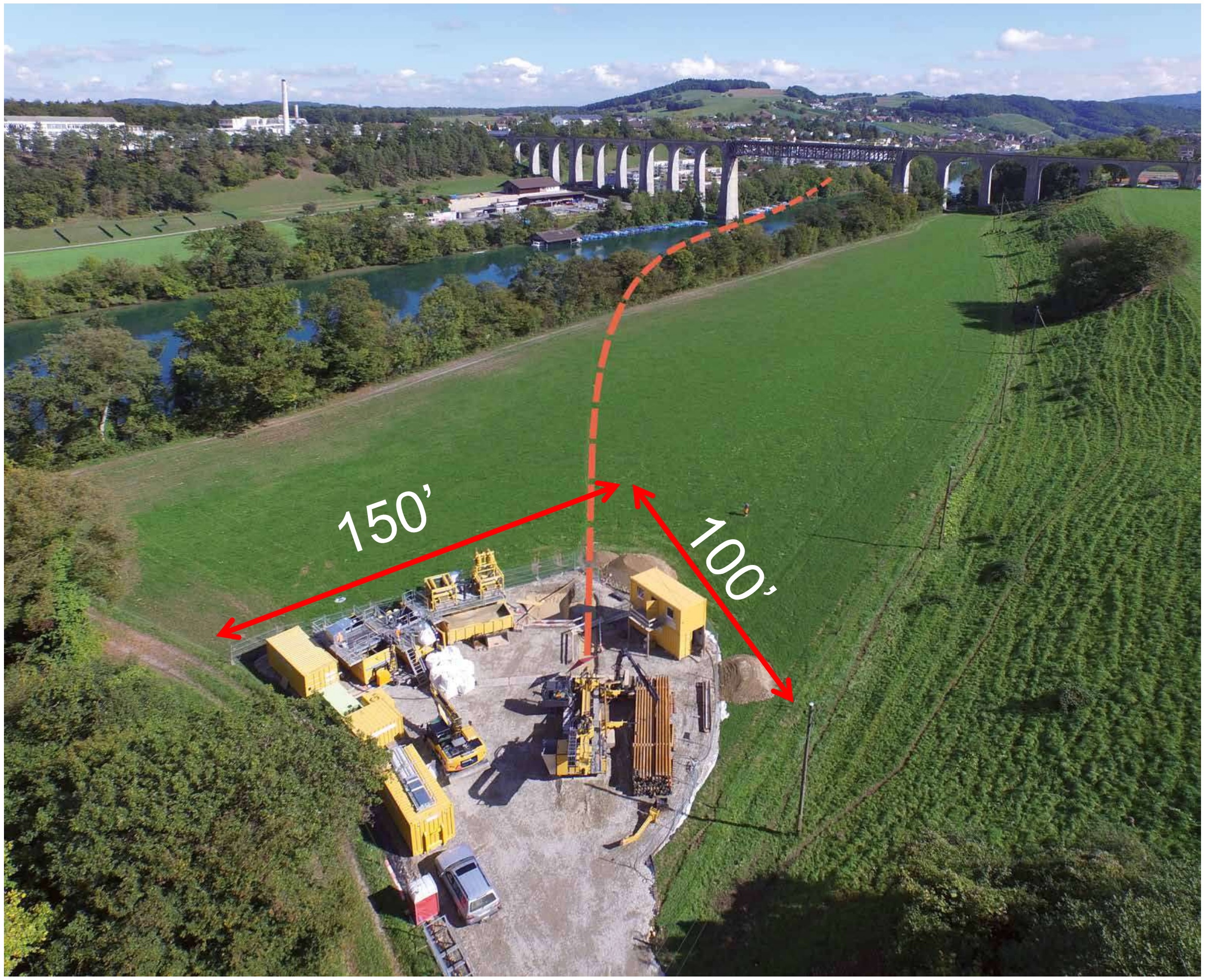
Drill Rig Setup Area

Recommended Size:
150 ft x 100ft

HDD Footprint – Maxi (Large) Rig Site

- Recommended footprint: 150 ft x 100ft
- Minimum width footprint: 42 ft x 225 ft





Maxi HDD Drill Rig Foot Print

Large HDD Drill Rig
>1,000,000 lb
Pullback Capacity

HDD Space Requirements

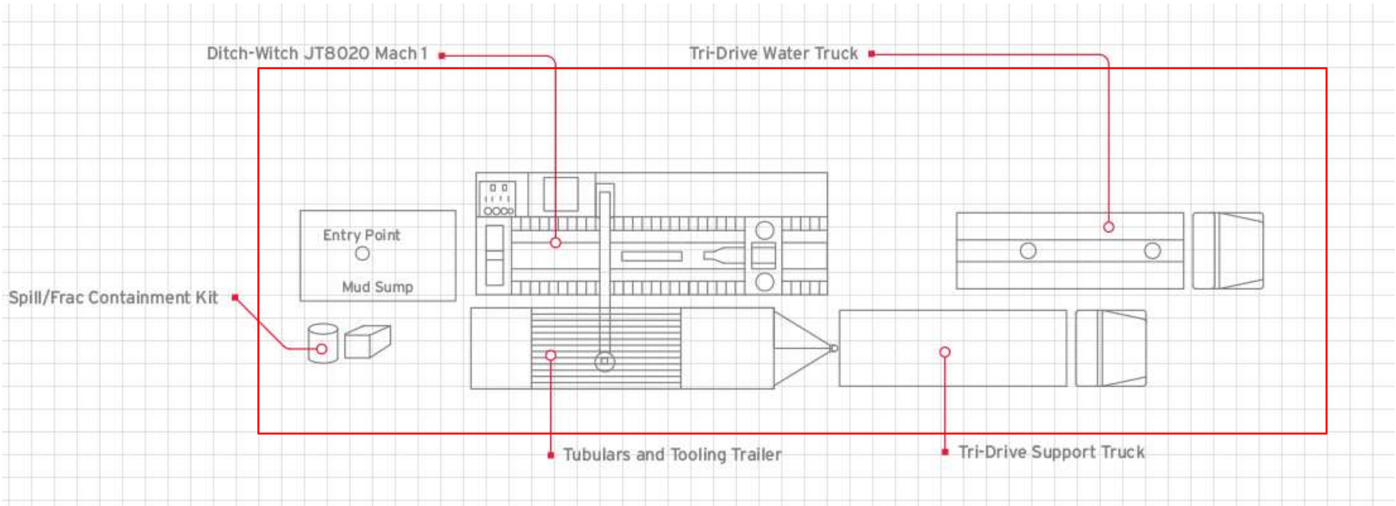
Midi (Medium) Drill Rig

HDD Footprint – Midi Rig

Drill Area

Recommended Setup: 115 ft x 50 ft area

Min Width Setup: 26 ft x 140 ft

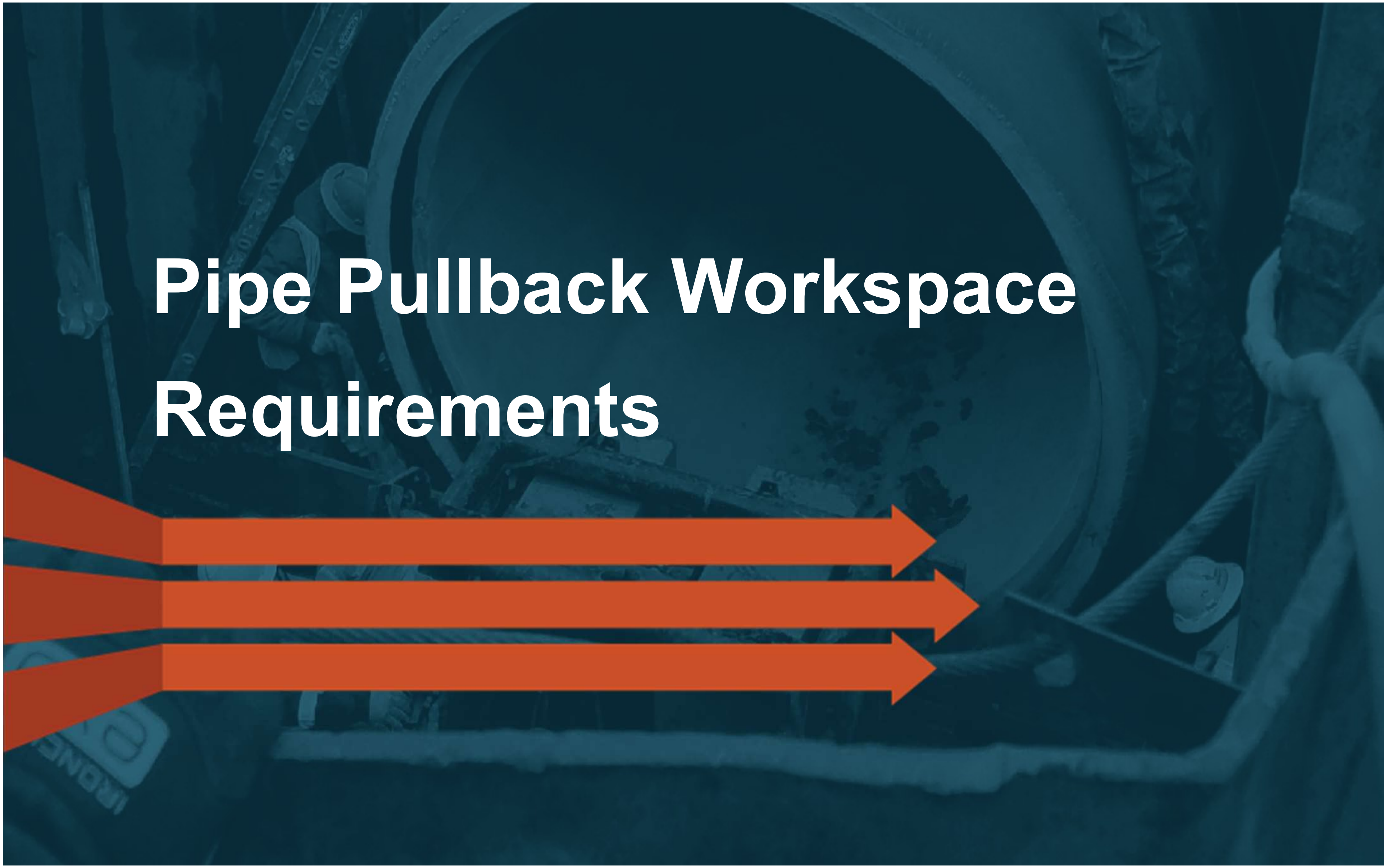


Midi (Medium) Drill Rig Footprint Example

New Compact-Size Midi HDD Drill Rig
100,000 lbs to 250,000 lbs Max Pullback

16" Force Main Crossing
Holston River
Knoxville Utilities Board, TN

Pipe Pullback Workspace Requirements



HDD Pipe Pullback Site – Large Diameter ≥ 24” OD

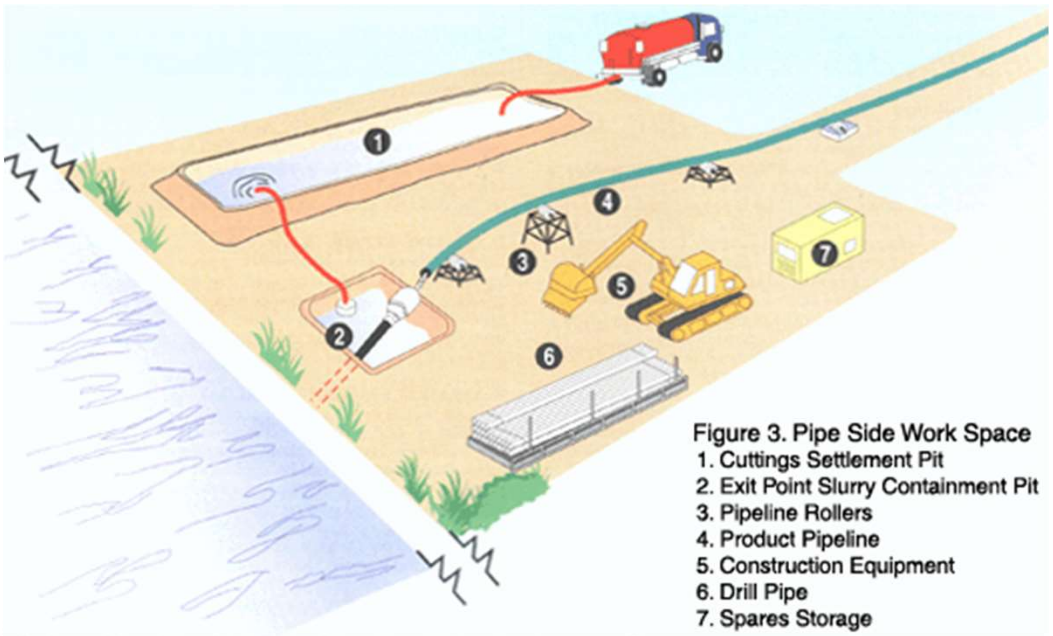
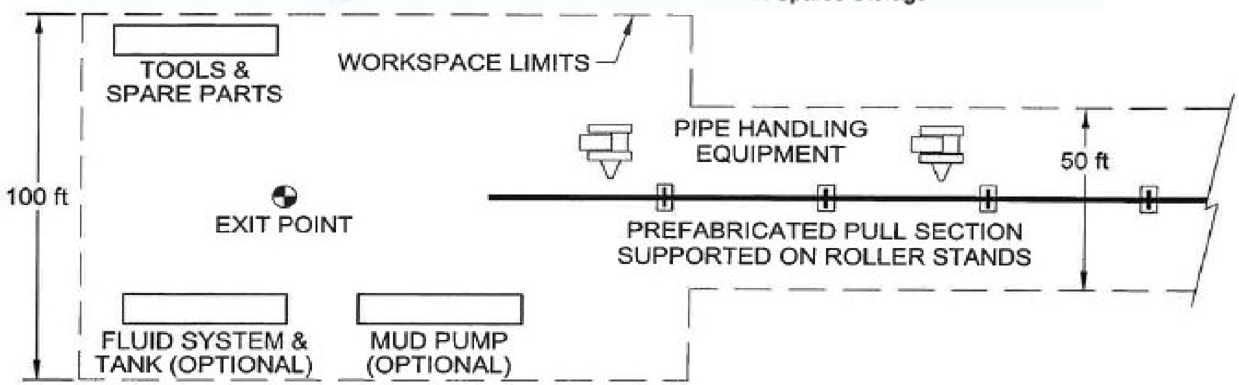


Figure 3. Pipe Side Work Space
1. Cuttings Settlement Pit
2. Exit Point Slurry Containment Pit
3. Pipeline Rollers
4. Product Pipeline
5. Construction Equipment
6. Drill Pipe
7. Spares Storage



<u>Activities</u>

1. Pipe String up
2. Drill Rod Daylight
3. Pipe Pullback

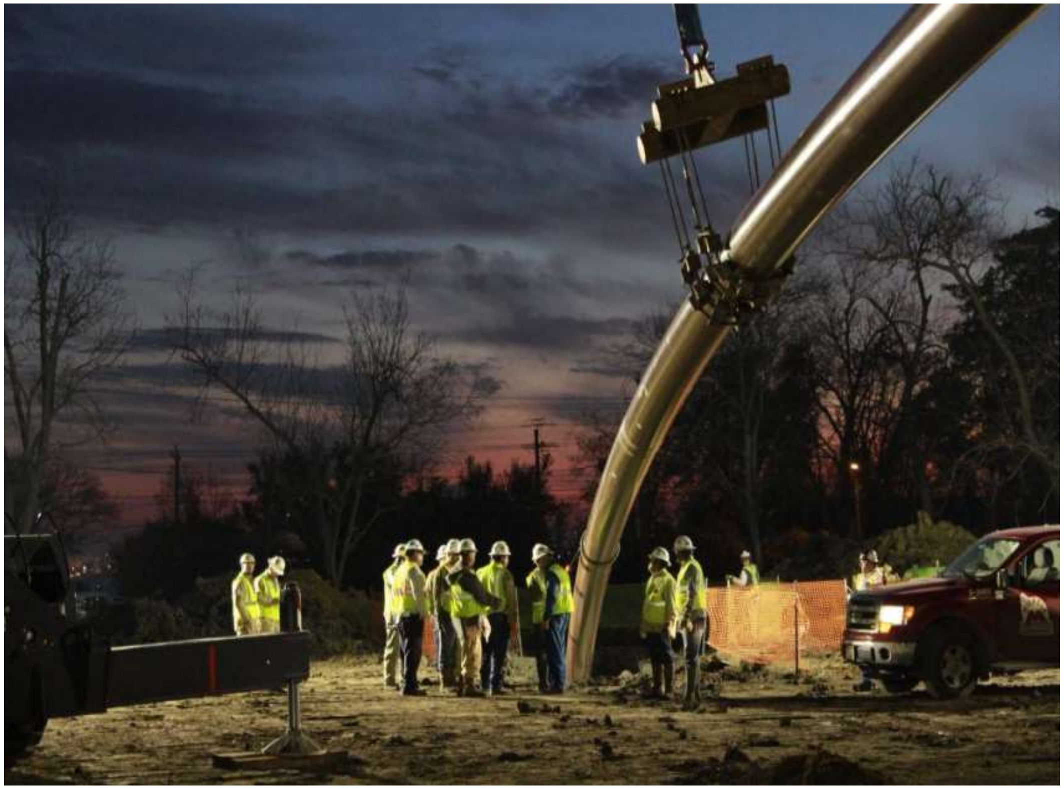
Recommended Workspace

1. Main Area: ~150’x100’
2. Pipe Laydown
   - Width: 35’-50’ W
   - Length: Drive Length
   - Length can be split up if needed but with increased risk

Pipe String-up and Laydown

HDD Pullback Site – Large Diameter (≥ 24” OD)

HDD Large Diameter Pipe Pullback Footprint



Hazen

Midi HDD Pipe Pullback Examples

Accuracy - Steering & Tracking

Steering

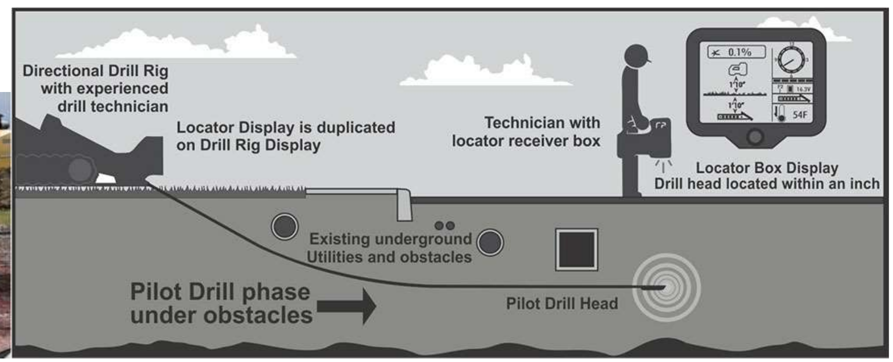
- Line & Grade Accuracy is Poor (±1% Max Depth of the Bore)
  - Typically Pressure Pipe Installations Only

Tracking

Walkover (Handheld)

Downhole Assembly Wireline (Survey Probe)

Wireline System (Surface Grid)



Rock HDD

Hard Rock is Possible

- >40,000 psi has been accomplished
- Uses High Velocity/Pressure to "Cut" Rock
- Mud Motor
- Downhole Percussion Air Rammers

Cost Impacts of Subsurface Conditions

HDD

Ground Conditions	Surveyed Cost ($/foot/inch)[1]	Average Increase
• Homogeneous • Firm Density, Cohesive Soils • Highly Weathered Rock	$15.43	N/A
• Homogeneous • Loose Density/Soft Soils	$27.76	180%
• Heterogeneous/Mixed Reach • Competent Rock	$40.11	260%
• Gravelly Sand, Gravel, Cobbles • Boulders, Obstructions	$76.81	500%

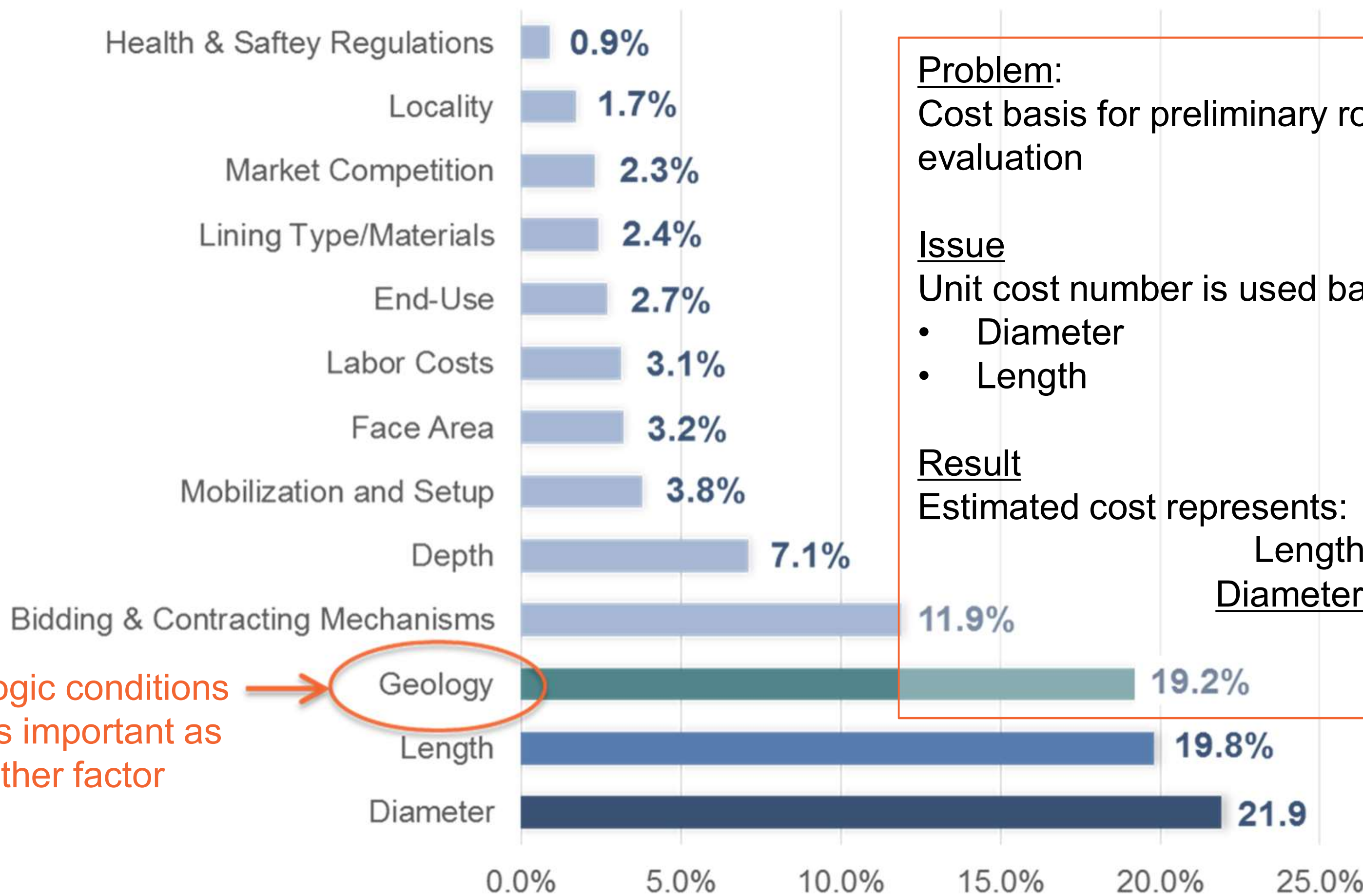
HDD pricing can range significantly 180% - 500% depending on geology and other site factors

[1] Costs in 2010 prices from surveyed municipalities

Reference: Vilfrant, Emmania; Arizona State University, *Analysis of Parameters Affecting Costs of Horizontal Directional Drilling Projects in the United States for Municipal Infrastructure,* December, 2010

Lessons Learned

What Drives Tunnel Cost?



Geologic conditions are as important as any other factor

Problem:
Cost basis for preliminary route evaluation

Issue
Unit cost number is used based on
- Diameter
- Length

Result
Estimated cost represents:
Length – 19.8%
Diameter – 21.9%
41.7%

Reference: Efron, Nathaniel; Read, Megan; Worcester Polytechnic Institute, *Analyzing International Tunnel Costs,* February 2012

What Drives Trenchless Costs?

Construction Cost = Materials + [Production Rates × Labor & Equipment Rates]

Hypothetical project – 2000 lf of 42” gravity sewer

Open cut cost

- **Production rate: 30-50 lf per day**
- Material per ft: $250
- Labor/equipment per ft: $330
- **Range: $1,030,000 - $1,335,000**
- **Variance: 30%**

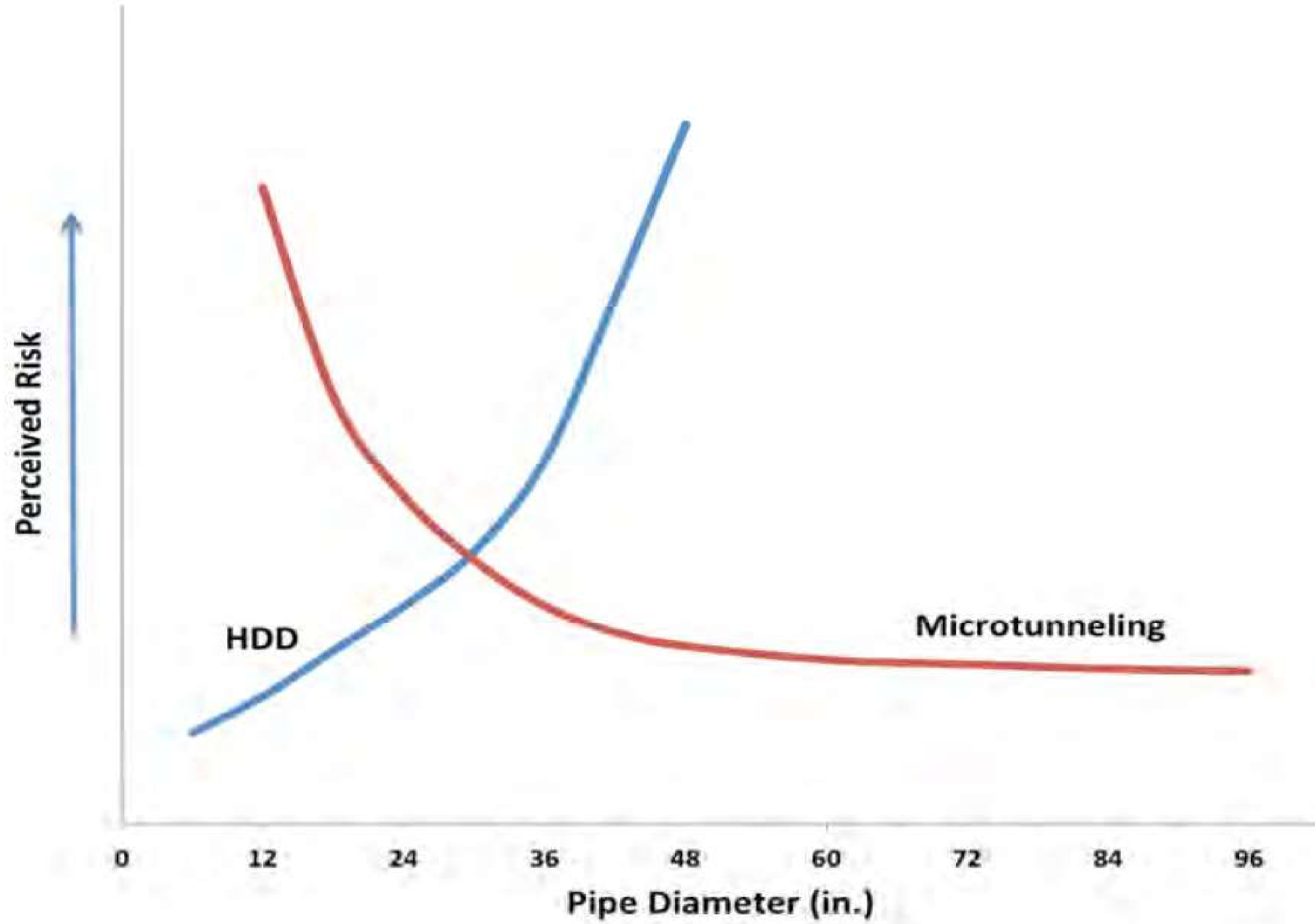
Tunnel cost

- **Production rate: 8-30 lf per day**
- Material per ft: $1,100
- Labor/equipment per ft: $800
- **Range: $3,300,000 - $6,200,000**
- **Variance: 88%**

The Right Tool for the Job

When You are a Hammer…

… Everything Looks Like Nail


Perceived Risk
HDD
Microtunneling
0
12
24
36
48
60
72
84
96
Pipe Diameter (in.)

To Avoid Paying for Unrealized Risks

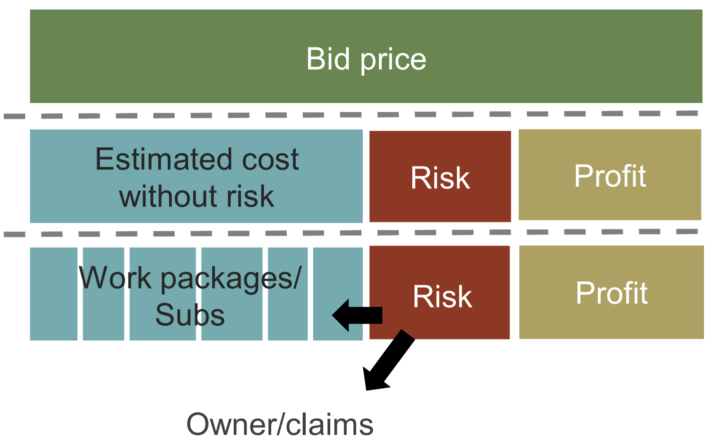
"Contractors don't absorb risk, they price it"

What the owner sees

What the contractor plans

Contractor continues to shed risk:

- Subcontractors
- Claims



To Avoid Paying for Unrealized Risks

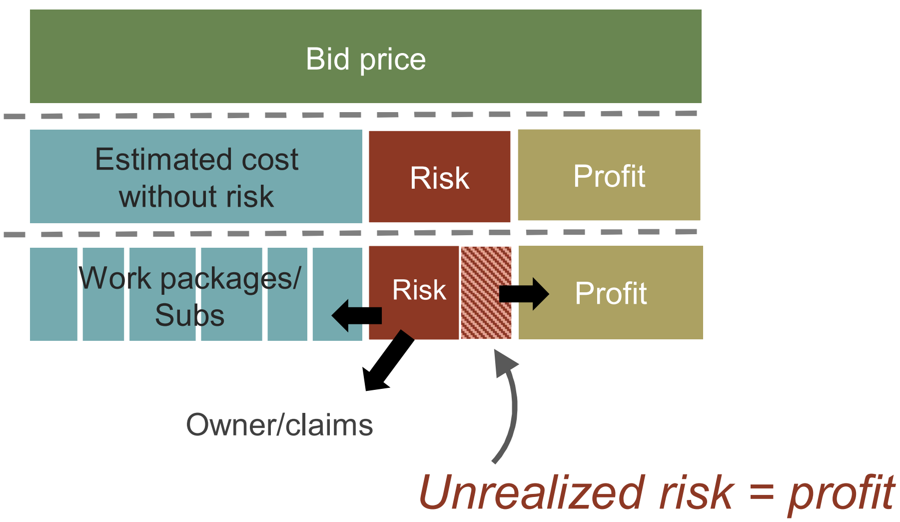
"Contractors don't absorb risk, they price it"

What the owner sees

What the contractor plans

Contractor continues to shed risk:

- Subcontractors
- Claims
- Unrealized risk



Contract: Engineer's Risk Management Tool

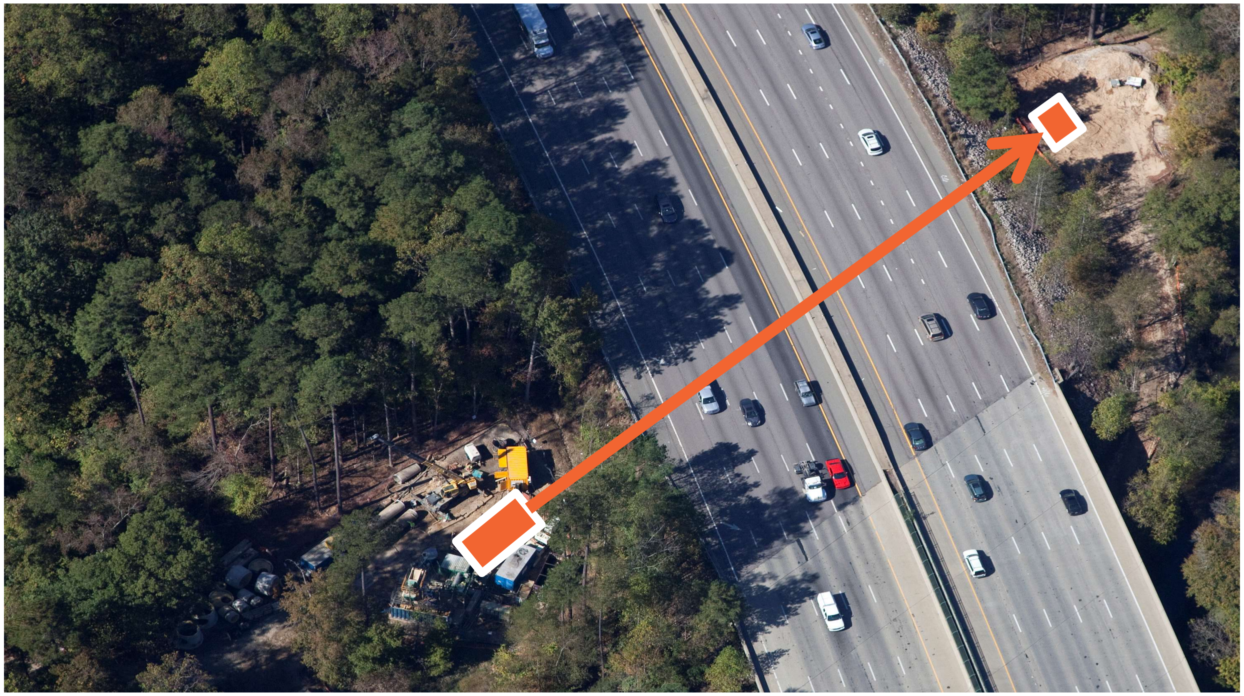
Performance based specification is often preferred

- $\neq$ Indemnification
- Limit/select methods
- Managing soils data
  - Shared interpretation
  - Limited reliance
  - DSC claim
- Allowances (unrealized risk)
- Definitions (stoppage procedures)
- Contingency planning
- Contractor experience (i.e.quals)

High-risk Ground Conditions

Boring Spacing

Highly variable



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Boring Spacing

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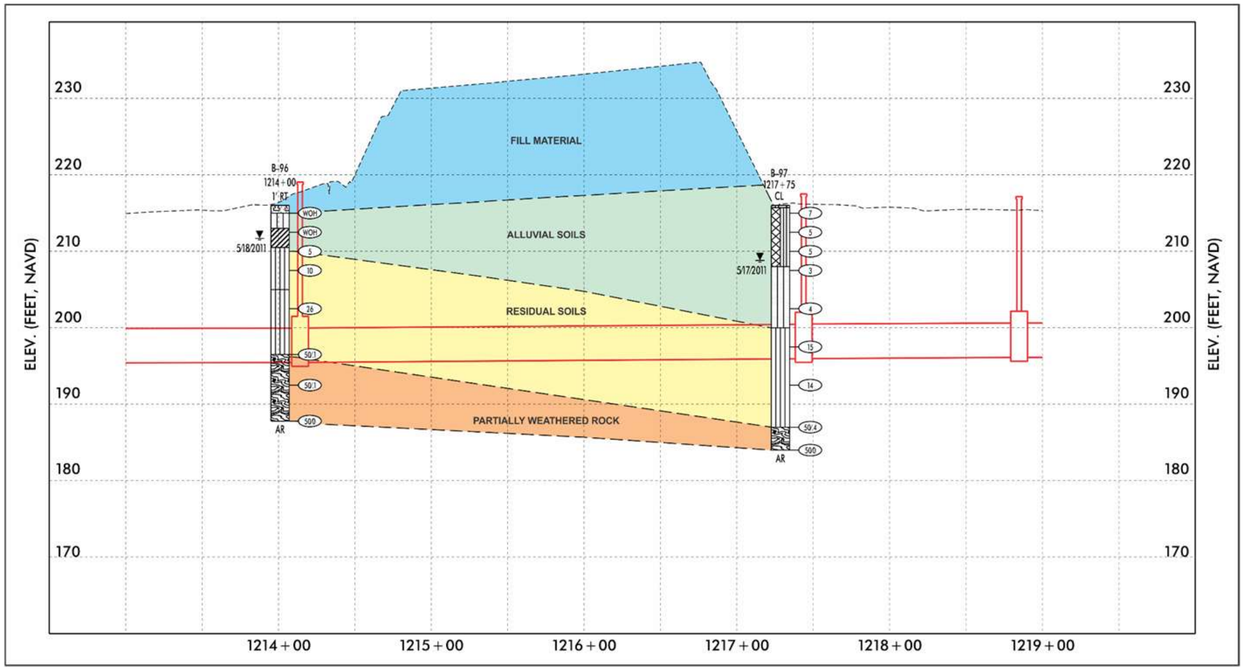

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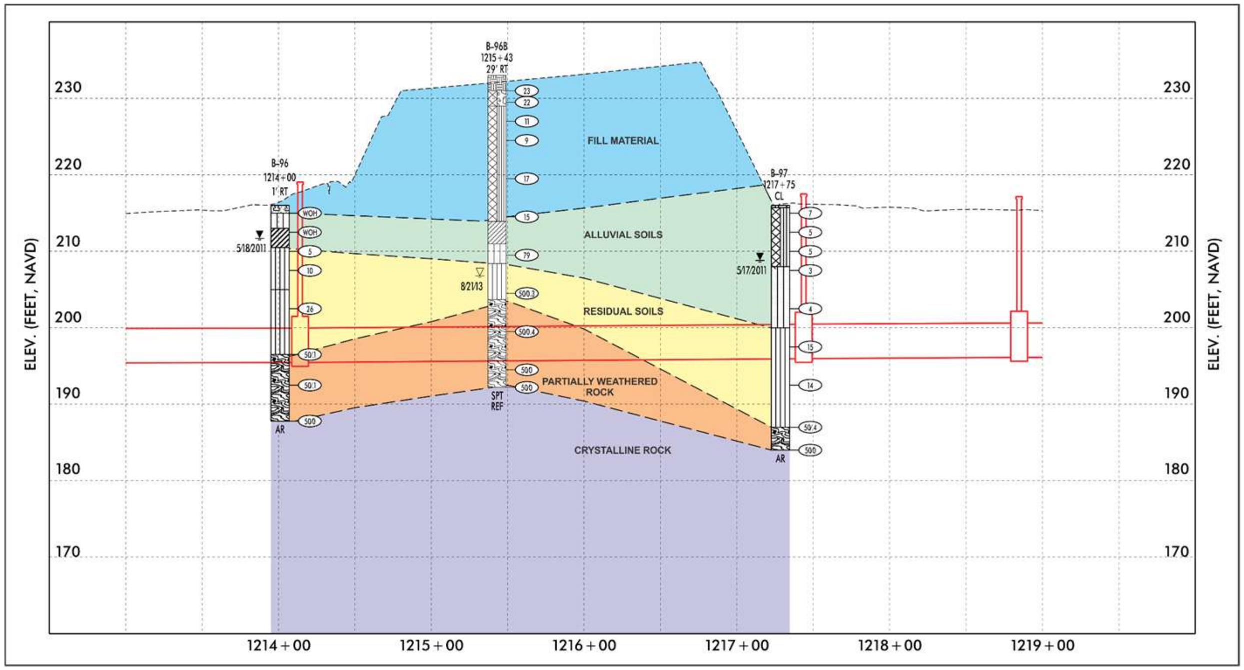
Highly variable



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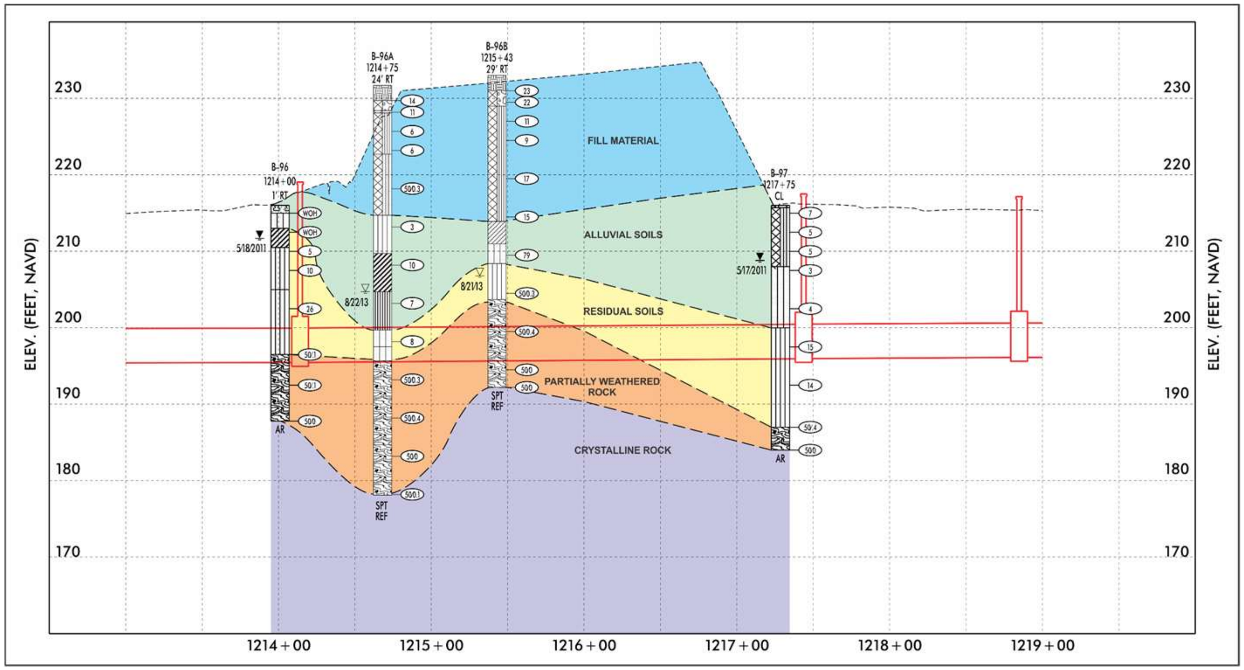

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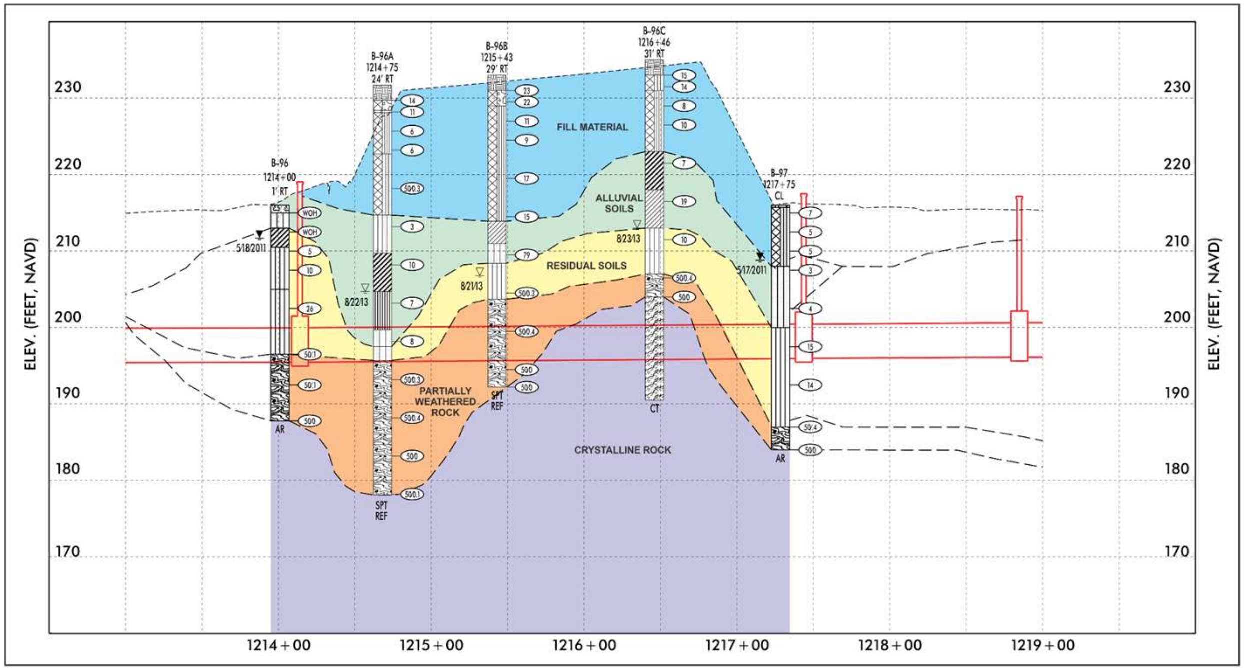
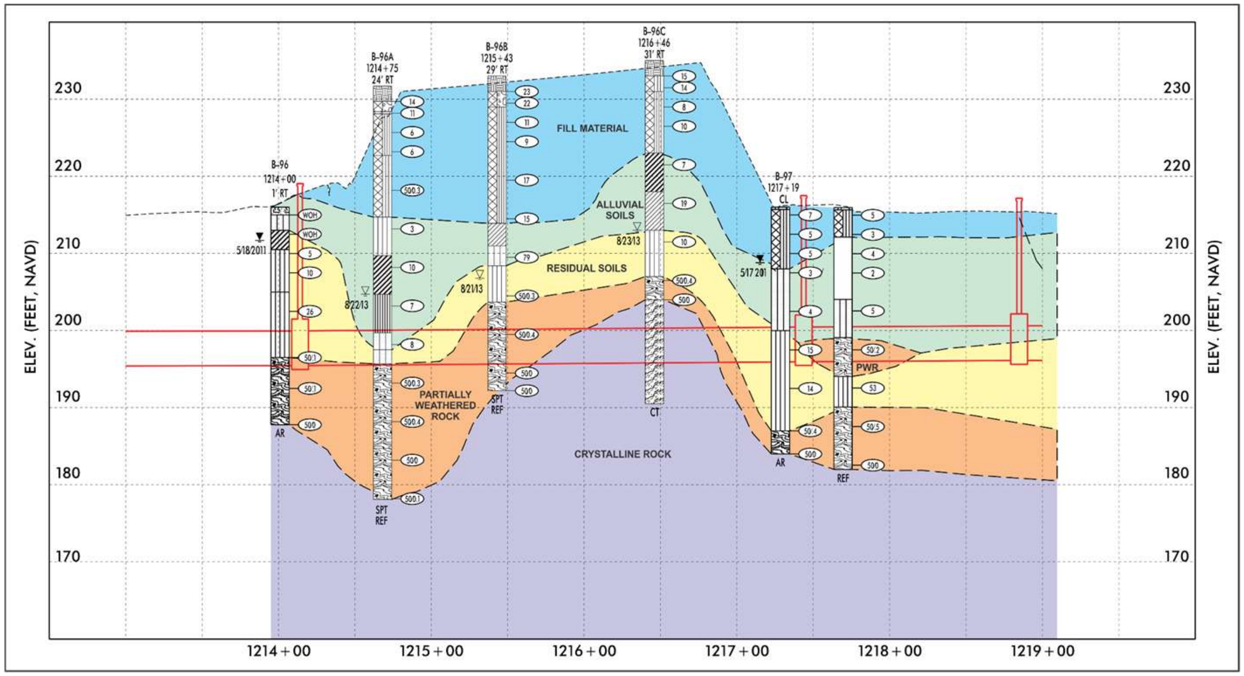
Highly variable



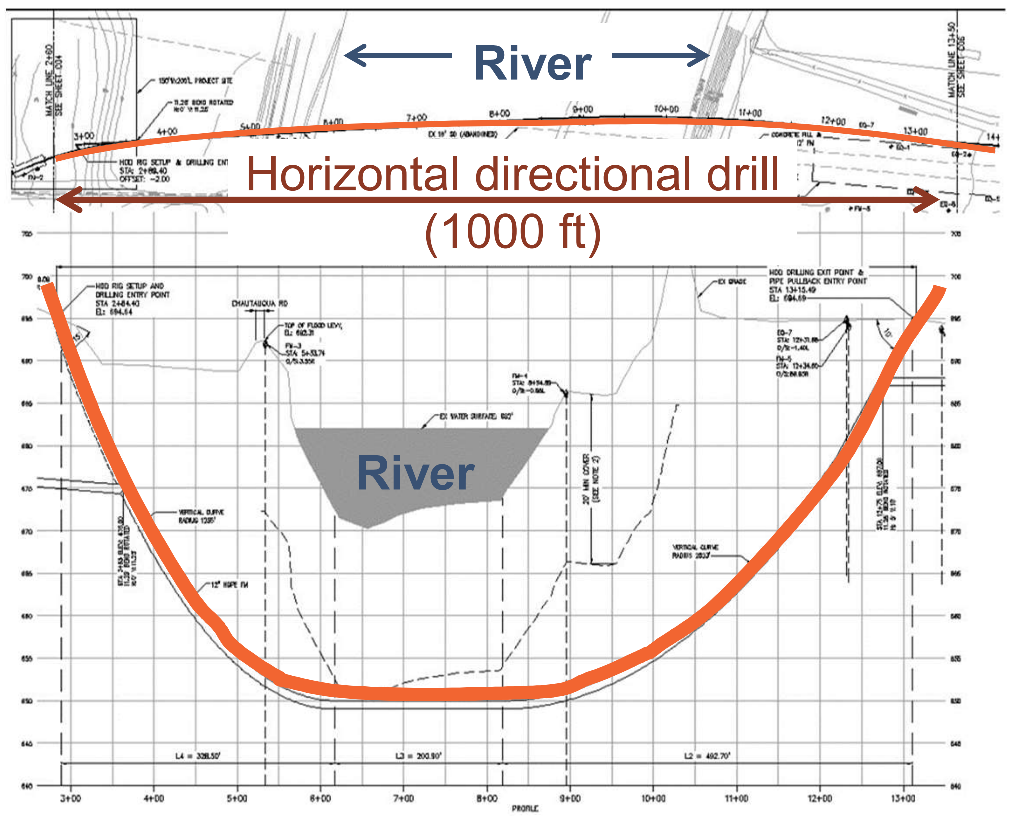
Boring Spacing

High-risk Ground Conditions

Highly variable



Obstructions

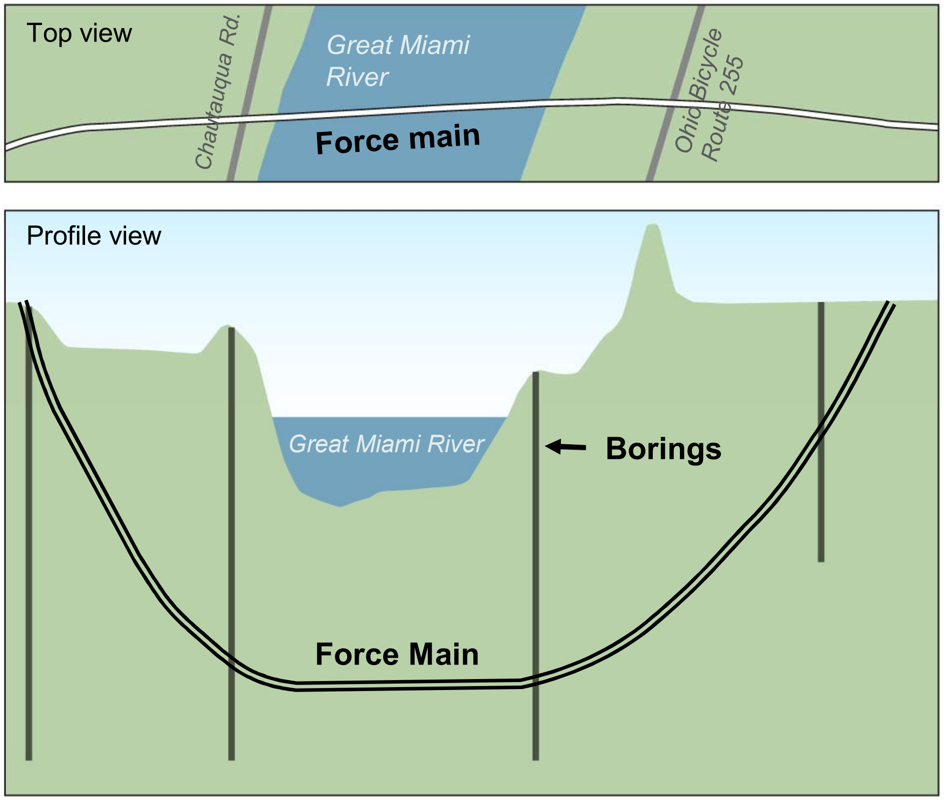


Subsurface Tool:

Electrical Resistivity Scan (ERi)

Alternatives to gathering soil borings only

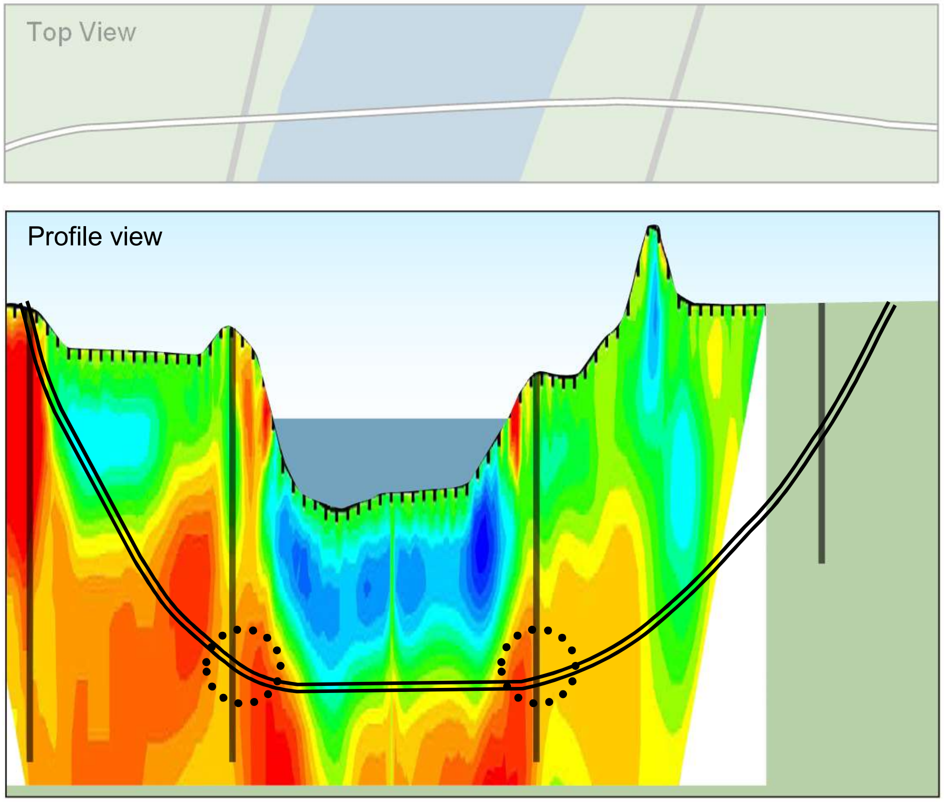
Obstructions



Subsurface Tool:

Electrical Resistivity Scan (ERi)

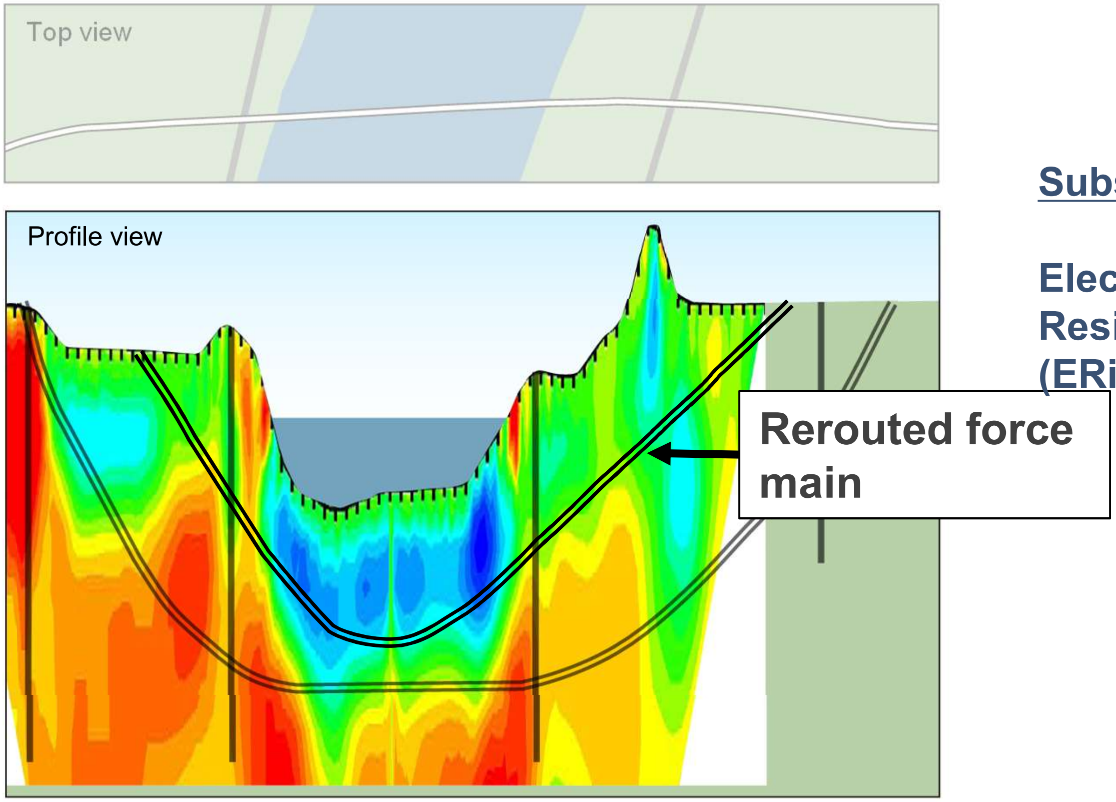
Obstructions



Subsurface Tool:

Electrical Resistivity Scan (ERi)

Obstructions



Subsurface Tool:

Electrical Resistivity Scan (ERi)

Josh Farmer

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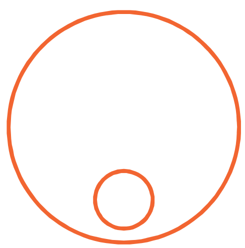
(919) 755-8561 (Office)

Hazen's Tunneling and Boring Corporate Technology Leader

Questions?

Trenchless Design Experience



20 Years

16" – 120"

50+ Miles

Methods Experience

- Microtunneling,
- HDD,
- TBM,
- Pipe Jacking w/Shield,
- Pipe Ramming,
- Guided Jack and Bore,
- Pilot Tube Auger Boring
- Hand Tunneling