Considerations for Planning and Implementation of Trenchless Methods for Water Conveyance Projects

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Agenda

- Background
- Overview of Methods
- Key Risks
- Profile Considerations
- Alignment Considerations
- Design/Construction Considerations
- Concluding Remarks

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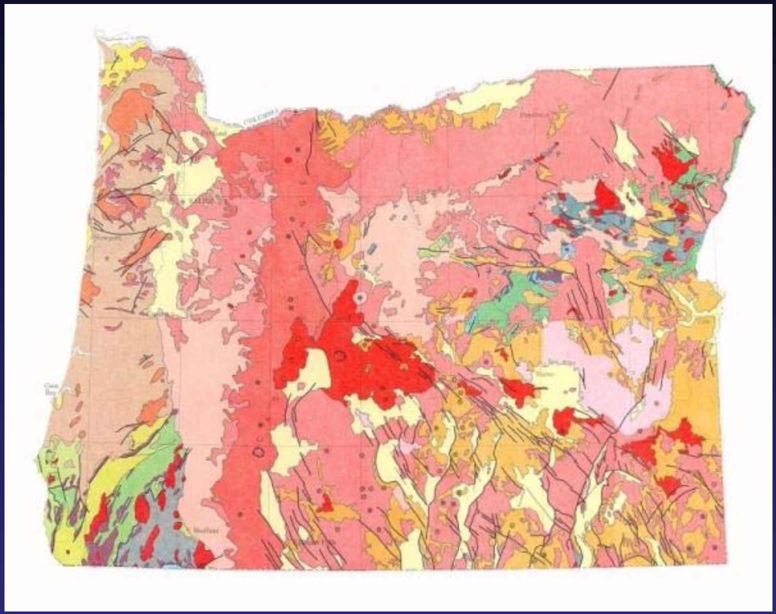
Geologic Background

- Complicated
- Challenging
  - Soft sediments and high groundwater near coast and lowland river crossings;
  - Highly variable flood deposits (from silt to boulders) in the Valley;
  - Boulders and shallow bedrocks on hills and highlands;
- Landslide risks
- Easier to predict than Puget Sound area



Typical Issues

- Unstable soils
- Obstructions
- Roadway and building settlement
- Utilities
- Traffic disruption
- Business disruptions
- Railroad coordination
- High groundwater
- Staging restrains
- Contaminated soil/water
- Concentrated impacts

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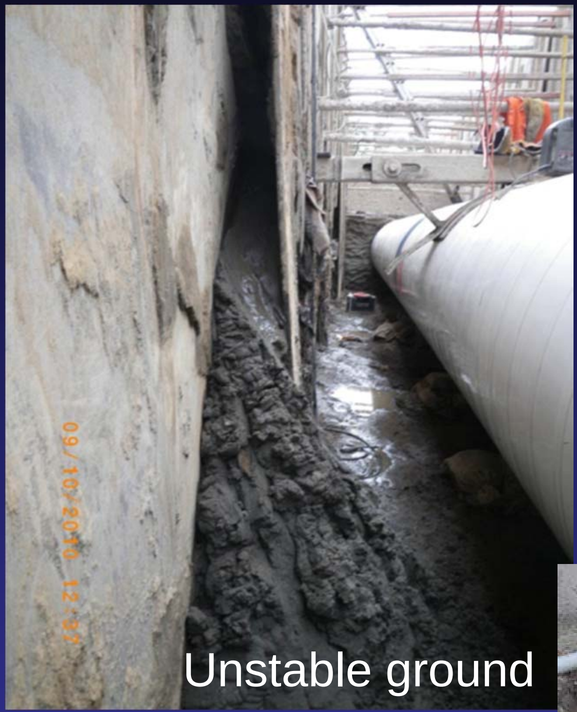
Open Cut Not Always the Answer



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Trenchless Methods

Method	*Typ. Lengths Installed*	*Diameters Typically Installed*	*Some Typical Unit Costs per foot*	*Remarks*
Directional Drilling	< 5,000’	4” to 54”	$700 - $1,200	Suitable for installation of water pipelines using a variety of pipe materials.
Auger Boring	< 300’	12” to 60”	$1,000 - $1,500	Typical for installation of short shallow casings at railroad and road crossings above the groundwater table
Pipe Ramming	< 400’	8” to 96”	$750 - $2,000	Suitable for installation of short shallow casings at railroad and road crossings.
Pipe Jacking	< 1500’	48” to 108”	$1,500 - $2,000	Suitable for installation of shallow to medium depth casings in good soil conditions generally above the groundwater.
Microtunneling	< 2000’	18” to 108”	$2,000 - $3,000	Suitable for installation of casings beneath water crossings and also other deep segments with poor soil conditions and high groundwater or in areas where settlement is a concern.
Conventional Tunneling	Unlimited	84” and larger	$2,500 - $3,500	Suitable for wide range or soil conditions above or below the groundwater level.
Hybrid Methods	SBU, Pilot Tube, Direct Jack, Guided Auger Boring			

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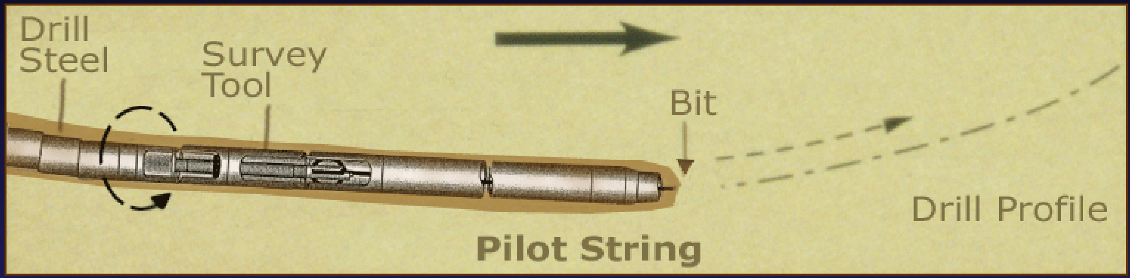
Typical Trenchless Design Tasks

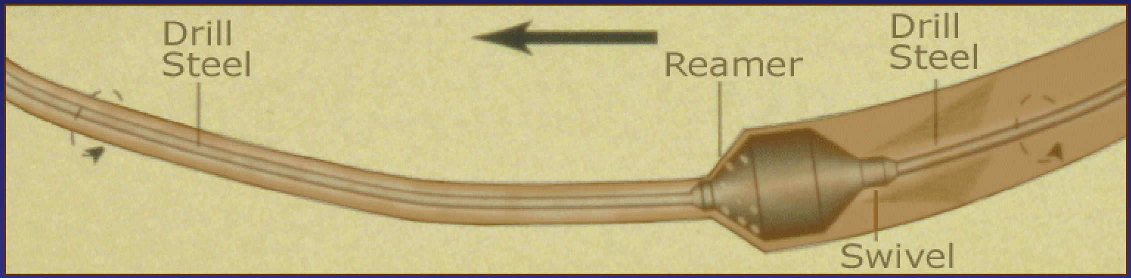
- Topographic survey along alignment
- Geotechnical exploration and testing
- Horizontal and vertical alignment selection
- Construction staging areas evaluation
- Accuracy and acceptable tolerances
- Spoils handling and disposal
- Product pipe design
  - Internal pressure, external pressure, backfill loading, tensile stresses, flexural stresses at bends, corrosion protection, testing
- Seismic factors such as liquefaction and lateral spreading;

Directional Drilling

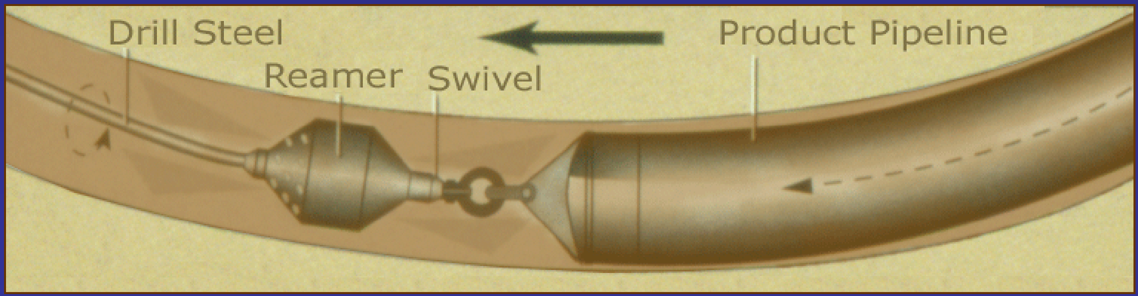
- Pilot bore



- Reaming to enlarge pilot borehole



- Pullback of product pipeline



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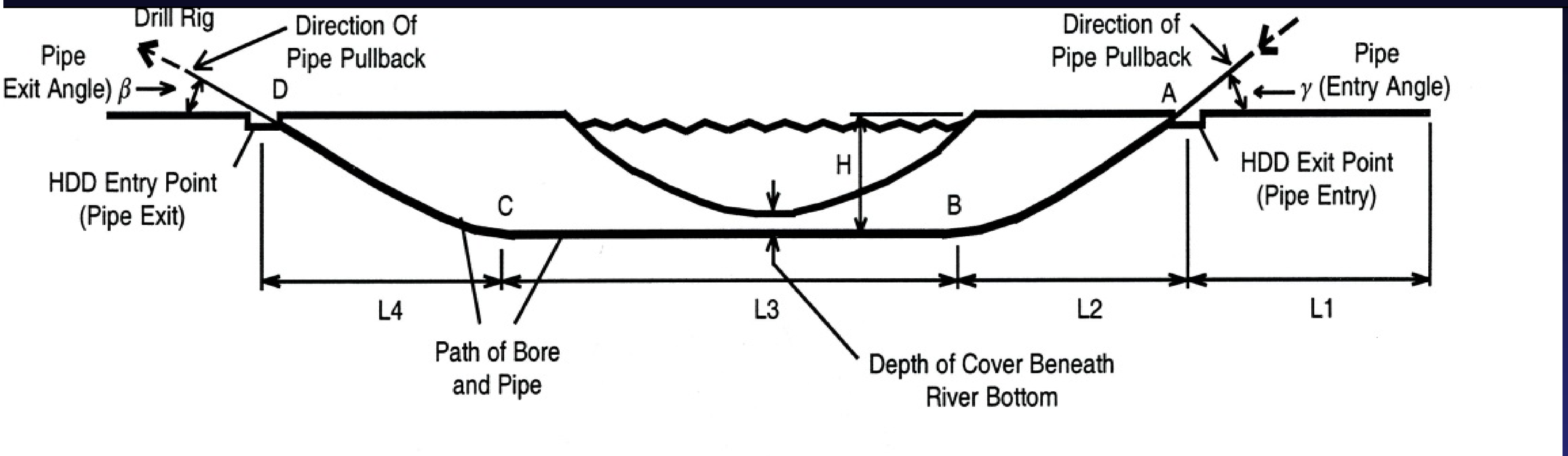
Typical Profile



- Entry & Exit Angles
  - Entry – 8 to 20 degrees (12 to 15 degrees are typical)
  - Exit – 5 to 12 degrees
- Bend Radius
  - HDPE - 20-25 times pipe OD in inches
  - Steel - 100 times pipe OD in inches
  - Drill steel – 1,200 x rod nominal diameter

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Auger Boring

- Road crossings
- Cohesive soils
- Medium distances
- Above water table
- Steel casing
- Crude steering
- Up to 72” (1.8 m)

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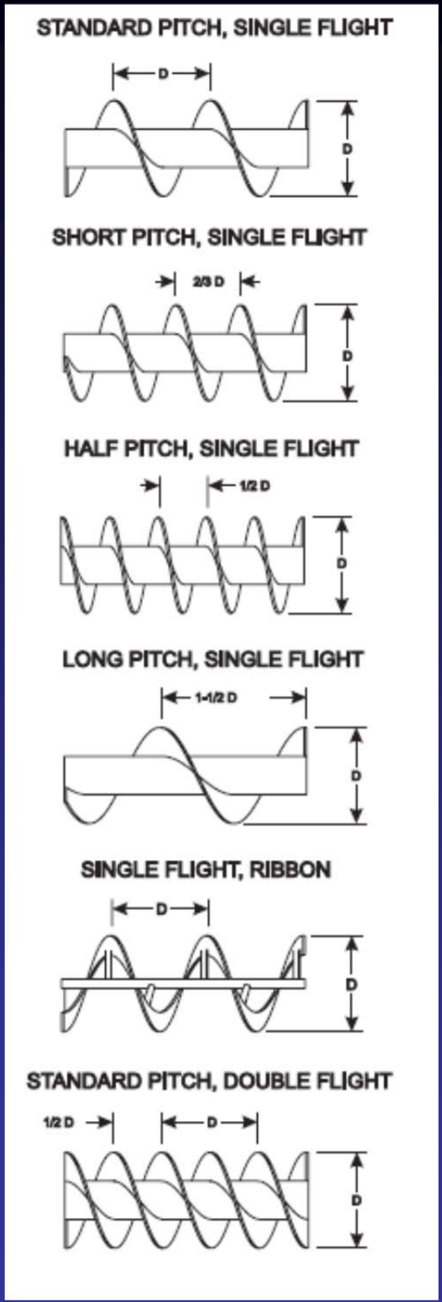
Augers

- **STANDARD PITCH, SINGLE FLIGHT**
  - Conveyor screws with pitch equal to screw diameter are considered standard.
- **SHORT PITCH, SINGLE FLIGHT**
  - Flight pitch is reduced to 2/3 diameter.
- **HALF PITCH, SINGLE FLIGHT**
  - Similar to short pitch, except pitch is reduced to 1/2 standard pitch.
- **LONG PITCH, SINGLE FLIGHT**
  - Pitch is equal to 1-1/2 diameters.
- **SINGLE FLIGHT RIBBON**
  - Conveying sticky or viscous materials.
- **STANDARD PITCH , DOUBLE FLIGHT**



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Pipe Ramming

- Wide range of diameters
- Soils only
- Continuously supported
- Typically < 300’
- Above and below water table
- Need steel casing
- No steering control
- Displaced soil volume is small (pipe wall + overcut only)
- Loose granular soils + vibration can lead to soil settlement

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Pipe Wall Thickness

Pipe Diameter (in)	*Thickness for Lengths less 60 feet (20 m)*	*Thickness for Lengths more 60 feet (20 m)*
6 – 12	0.25”	0.27”
14 – 20	0.31”	0.39”
24 – 40	0.47”	0.55”
42 – 51	0.62”	0.70”
54 – 66	0.75”	0.87”
72 – 96	1”	1.25”
108 – 120	1.13”	1.5”

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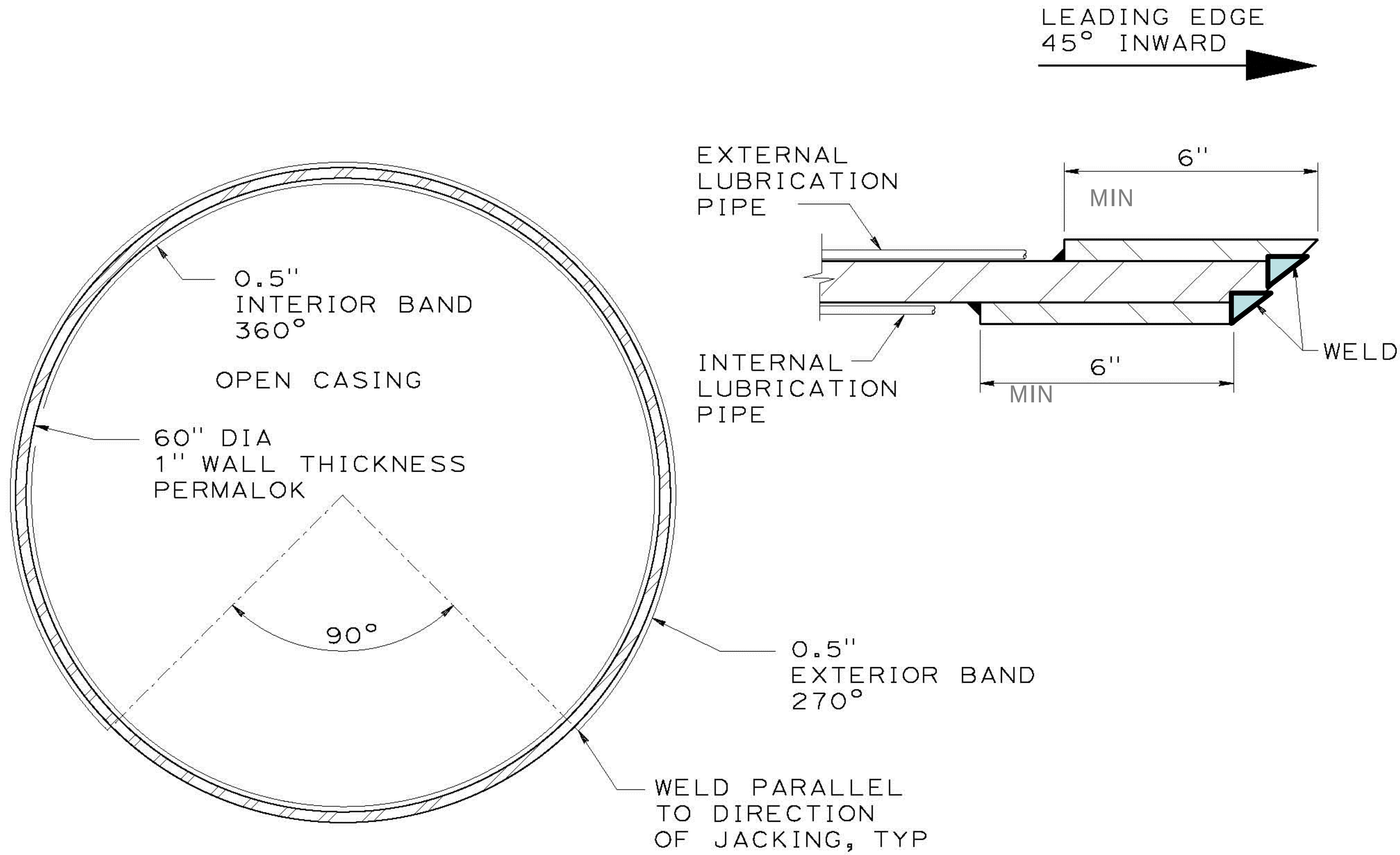
Leading Edge Details



Typical Hammer Sizes

Tool Diameter (in)	*Recommended Pipe Diameter (in)*	*Maximum Length (ft)*
5	2 – 8	80
7	8 – 20	115
8.5	12 – 20	130
10.5	15 – 32	165
14	20 – 48	230
18	24 – 56	265
24	56 – 78	265
32	56 – 122	300

Pipe Jacking

- Larger diameters
- Personnel entry
- Soft ground
- Variable face support
- Long distances
- Above water table
- Steerable
- Pipe provides ground support and transmits forward thrust
- Includes jacking system for thrust

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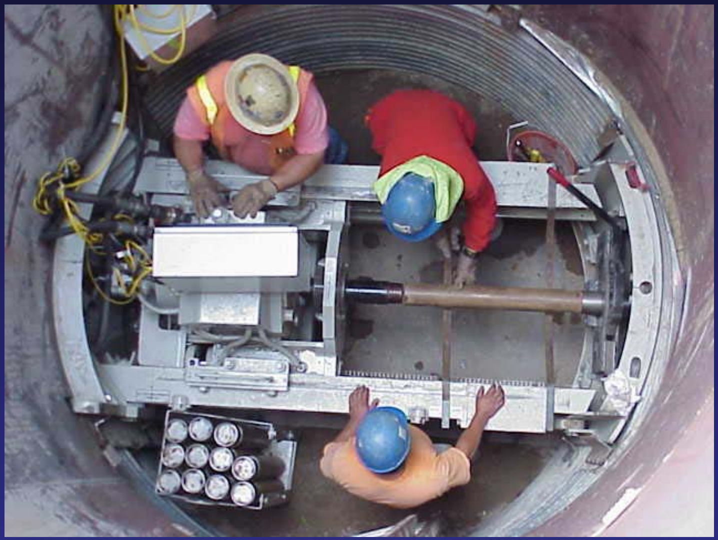
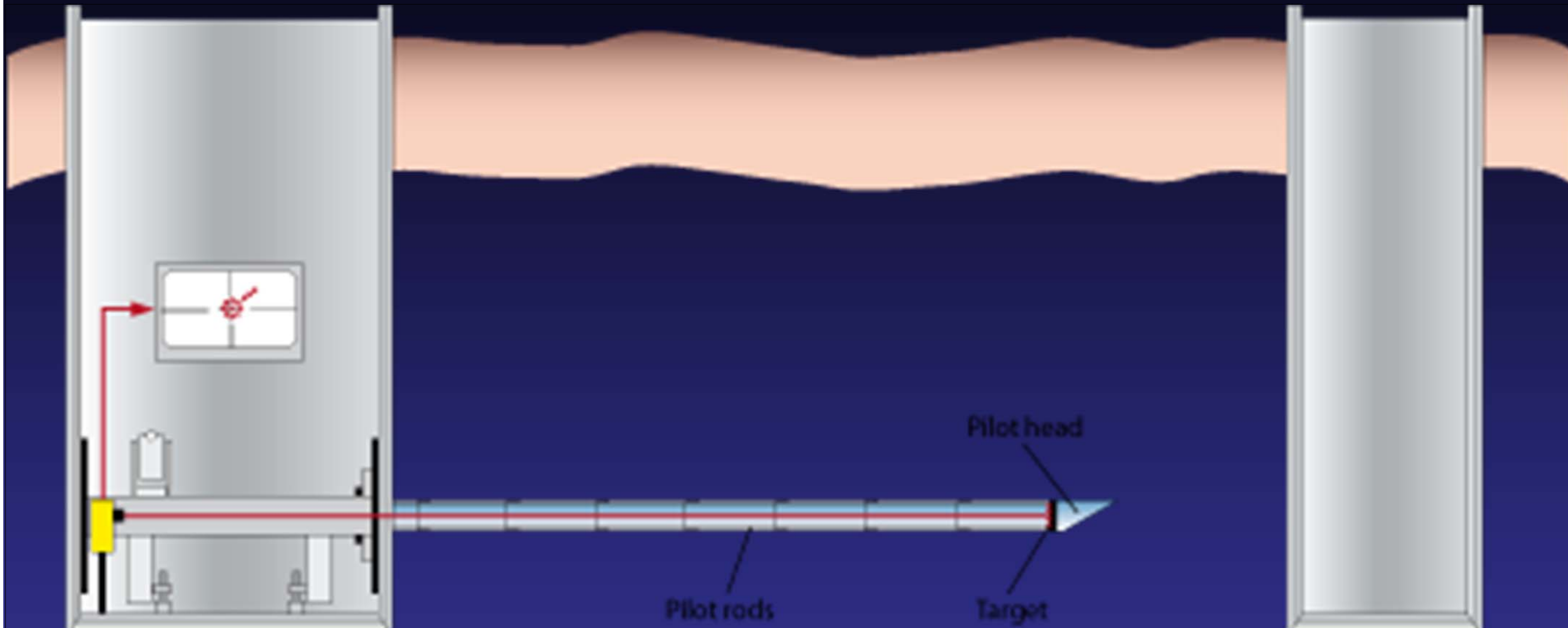
Pilot Tube Method

- Multi-pass method used to install relatively small diameter pipes
- Needs minimal equipment
- Uses small diameter shafts
- Needs displaceable soils
- Limited jacking capacity of 80 tons
- Typical installation is 250 feet
- Has attributes of:
  - HDD
  - Auger Boring
  - Microtunneling



First Pass



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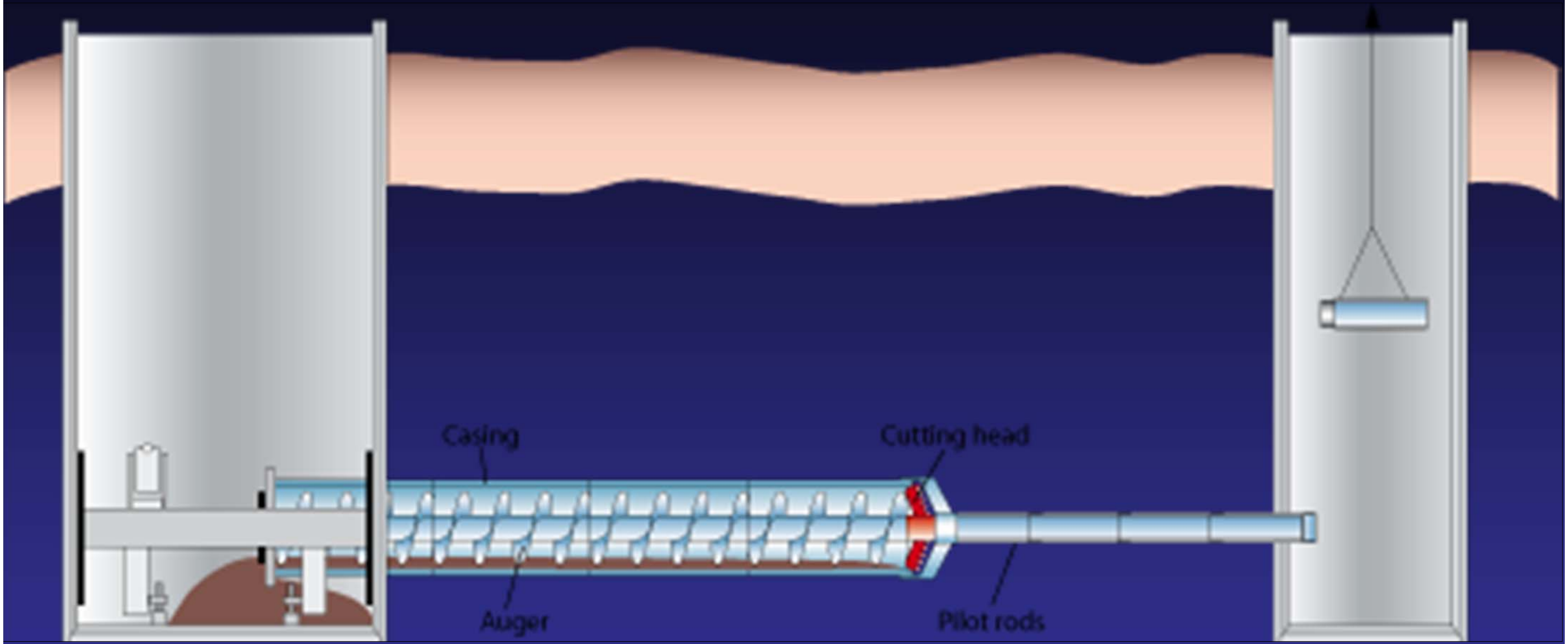
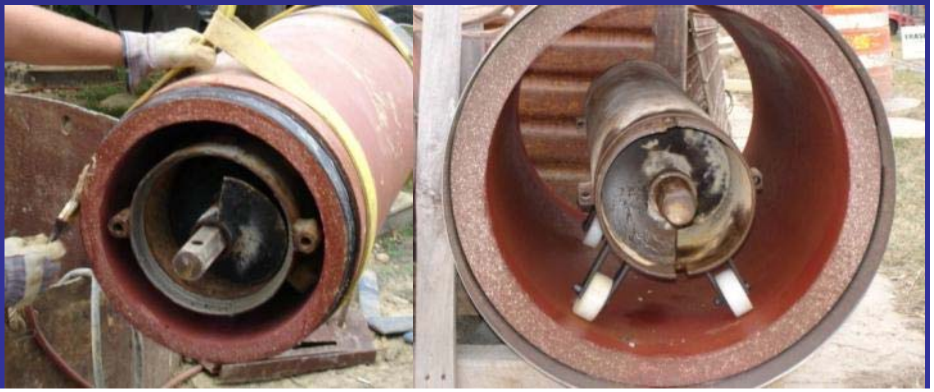
Second Pass



Ream to desired diameter



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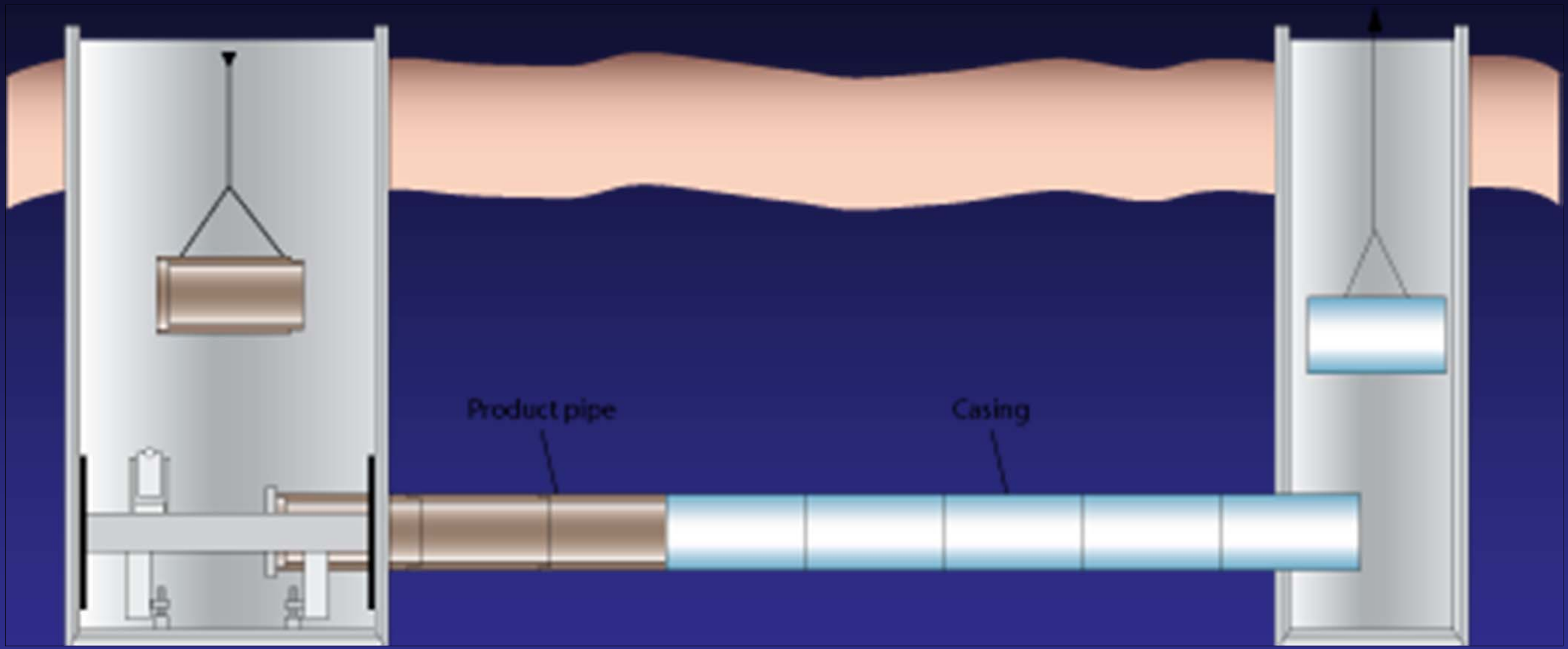
Third Pass



Install the casing/carrier pipe

Guided Pipe Ramming

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Guided Auger Boring

Down the Hole (DTH)

- DTH uses a horizontal hammer inside the steel casing
- Used with harder rock conditions and boulders

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Small Boring Unit (SBU)

- Full face rock (include boulders)
  - Rock quality
  - Blocky
  - Fissures/seams/bedding
- Get the unconfined compressive strength (UCS) (up to 25 ksi)
- Determine the mineralogy

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Microtunneling

- Regionally proven pipeline construction method
- Range of diameters (>36”)
- Most ground types
- Continuous face support
- Long distances
- Below water table
- Range of pipe materials
- Steerable to line and grade
- Remotely operated

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Influence of Geotechnical Conditions on Microtunneling

MICROTUNNELING FACTORS	Soil Type	Strength	Grain Size	Groundwater Conditions	Plasticity	Compressibility	Obstructions	Mixed Face Conditions
Machine Type	●	●	●	●	●		●	●
Production Rate	●	●	●	●	●		●	●
Jacking Loads	●	●	●	●				
Drive Lengths	●	●	●	●				
Line-and-Grade Control		●				●	●	●
Solids Seperation	●		●		●			
Settlement Potential	●	●	●	●		●		
Pipe Support	●	●			●	●		
Jacking and Receiving Pits	●	●		●			●	●
Thrust Block Resistance	●	●				●		

Pipe Ramming and Microtunneling

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Risks

Early Identification Of Risk

- Understand Risks
  - Subsurface
  - Site Constraints
- Develop risk reduction strategies
- Identify opportunities

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Historical Risks Associated with Trenchless Construction

- Gravel, cobbles, and boulders stop advancement
- Abrasive soils cause excessive wear & tear
- Slurry/drilling fluid management issues in open gravels
- Hole instability and ground loss in loose sands
- Debris/obstructions stop advancement
- Steering and ground support difficulties at transition between relatively soft ground into hard ground
- Steering and pipe/machine support due to soft ground
- Loss of slurry circulation including inadvertent returns (hydrofracture)
- Groundwater control at shafts

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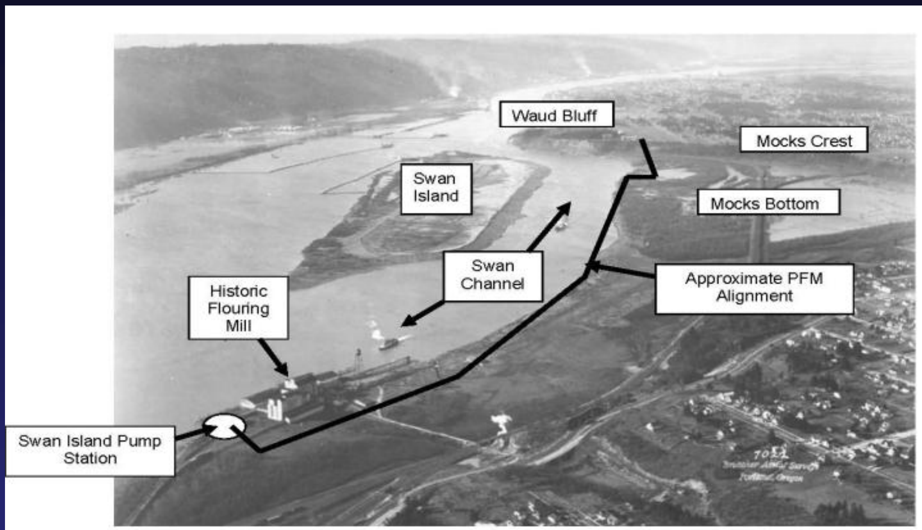
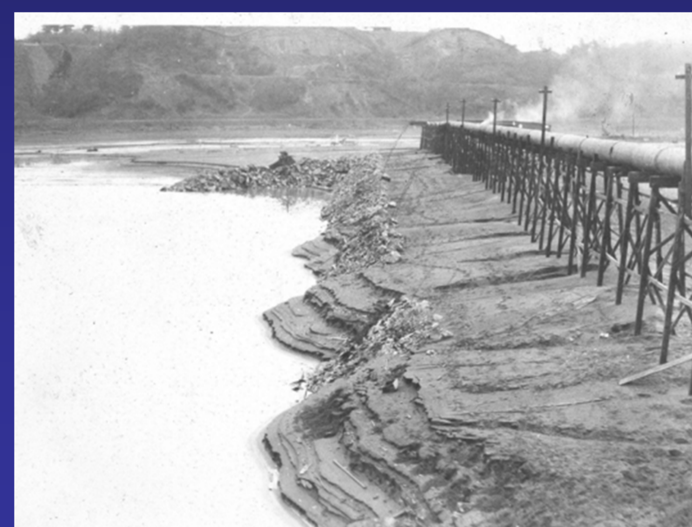
Owner Owns the Ground

- Explore it
- Reject it (and select a different alignment)
- Ignore it
- Baseline it

Site History





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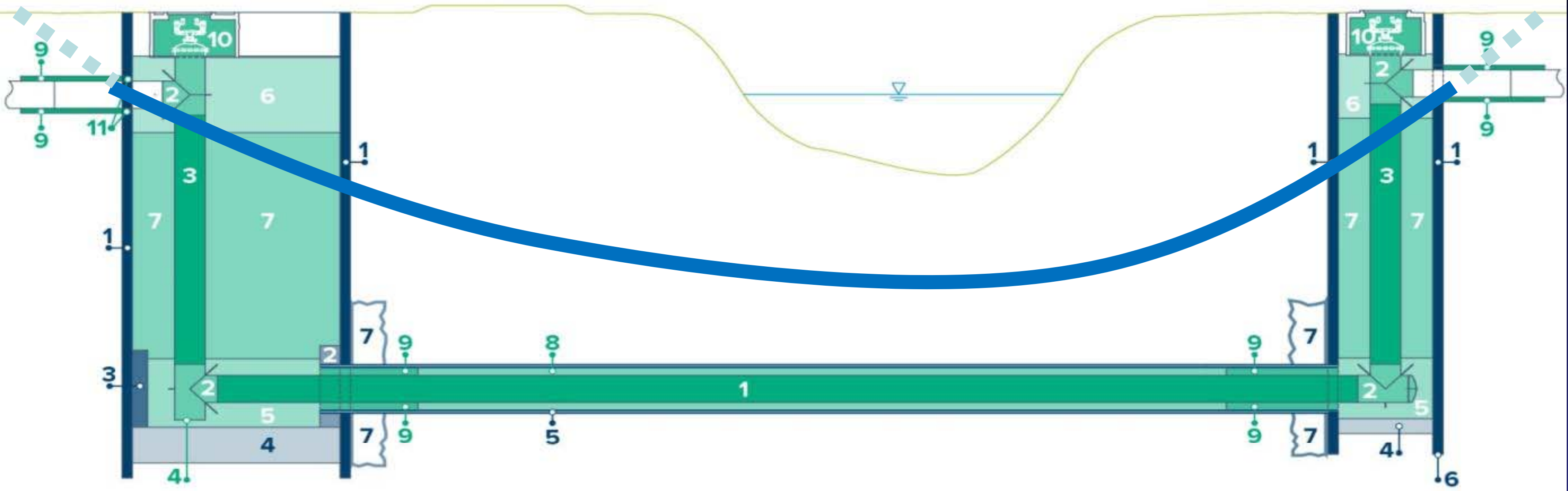
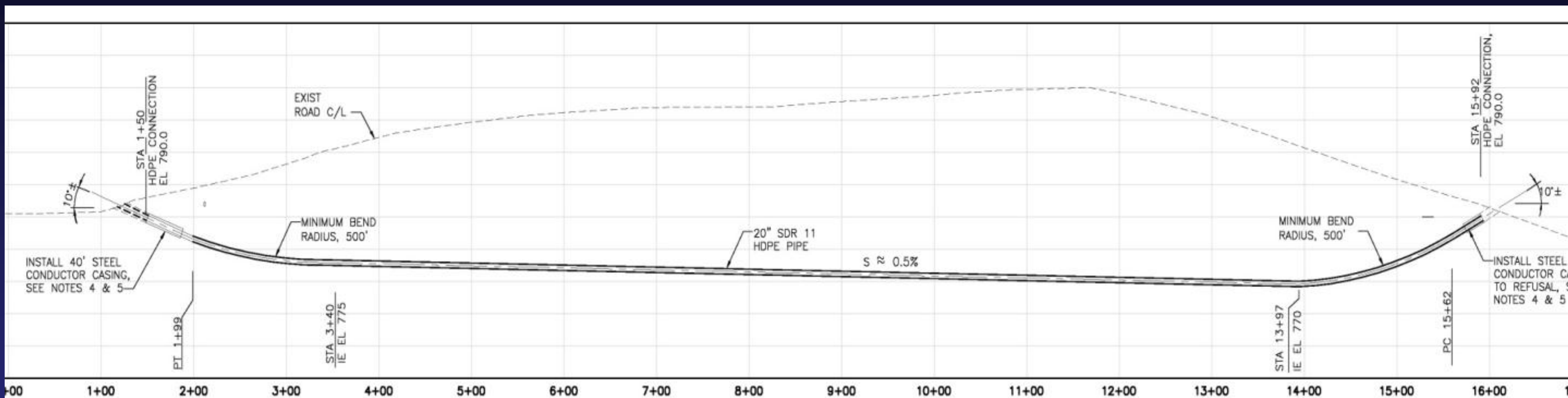
Typical Trenchless Profiles

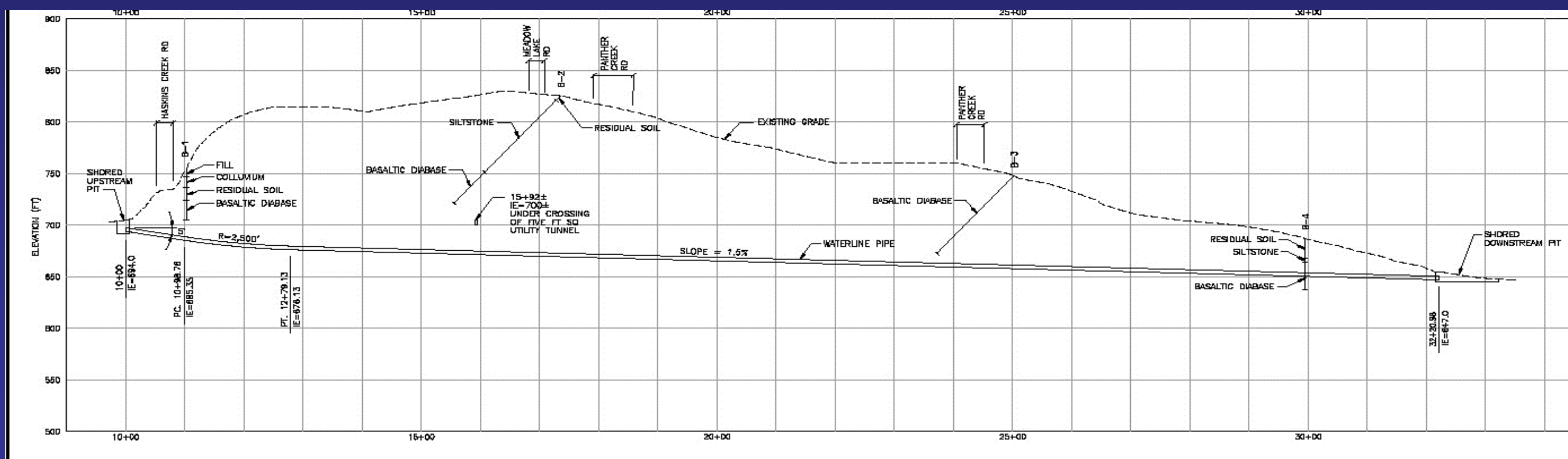


Construction Elements	
1	Shoring Wall System
2	Shaft Wall Seal
3	Tunnel Thrust Block
4	Shaft Base Slab/Seal
5	Tunnel Casing
6	Shaft Groundwater Cutoff
7	Ground Improvement

Permanent Elements			
1	Tunnel Pipeline	8	Annular Space Backfill
2	Pipeline Elbow/Tee	9	Concrete Pipe Encasement
3	Pipeline Riser	10	Access/Air Vac Structure
4	Low Point Sump	11	Pipe Wall Penetration
5	Lower Shaft Pipe Encasement		
6	Upper Shaft Pipe Encasement		
7	Shaft Backfill		

HDD Profile Options





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Guidance

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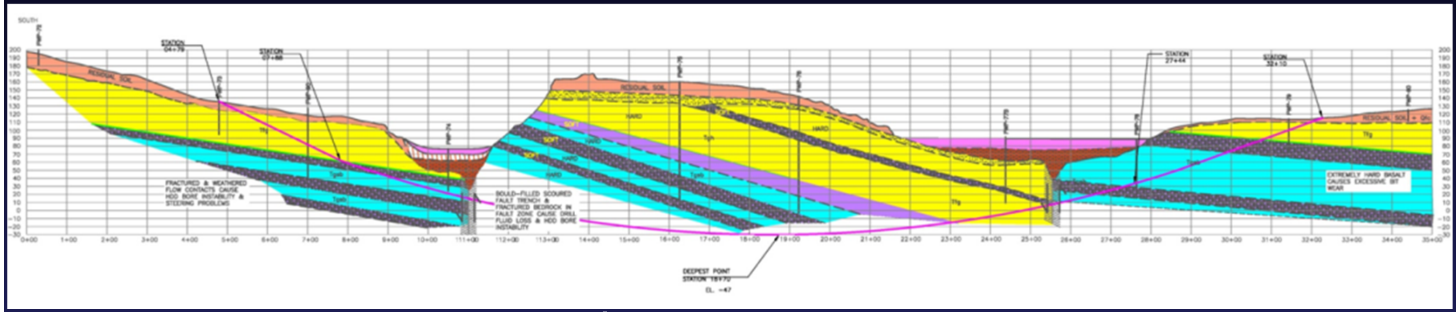
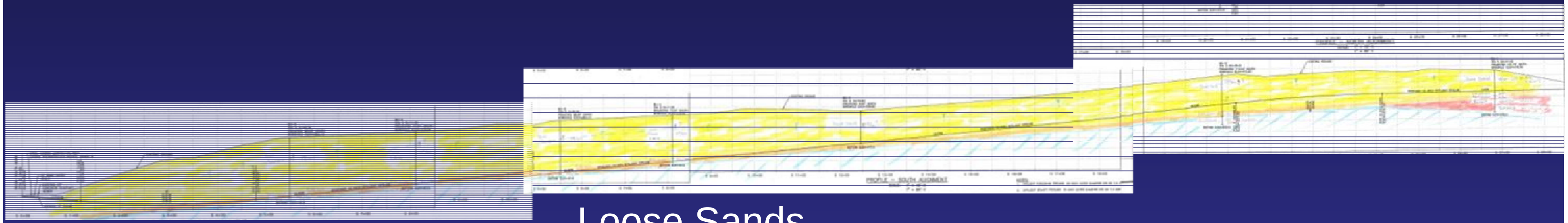
Geologic Bad Actors

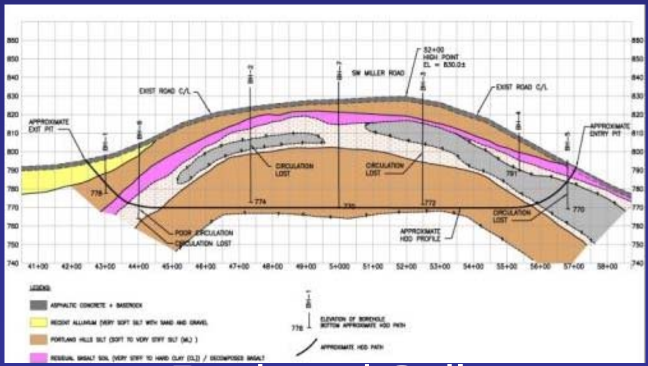


Shear Zones

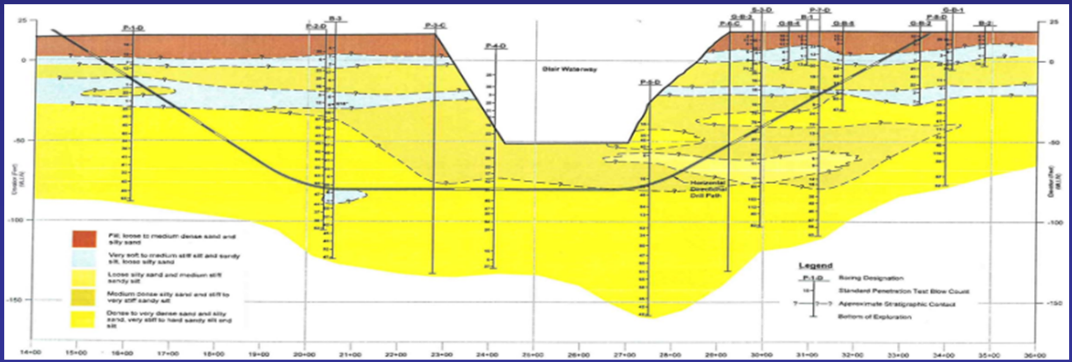
Magnetism



Loose Sands



Rock and Soil



Stratified Sand and Silt

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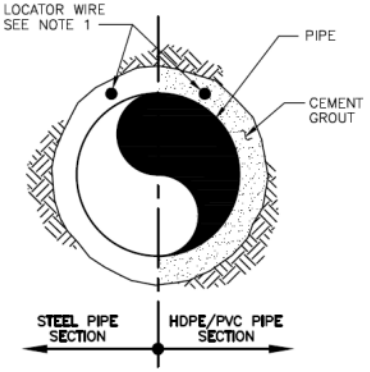
Pipe Material Influences HDD Profile



MINIMUM TUNNEL DIAMETER

PIPE MATERIAL	PIPE O.D.	MINIMUM TUNNEL DIAMETER
HDPE	42.0"	54.0"
STEEL	37.0"	48.0"
PVC	38.3"	50.0"

NOTES:

1. MINIMUM OF TWO LOCATOR WIRES SHALL BE PULLED WITH HDPE OR PVC PIPE. STEEL PIPE DOES NOT REQUIRE LOCATE WIRE. OFFSET WIRE MIN. 2'.
2. IF HDPE OR PVC PIPE IS SELECTED, ANNULUS SPACE SHALL BE BACKFILLED WITH CEMENT GROUT.

TYPICAL TUNNEL SECTION 1 —
NTS

Pipe Property	Steel	Fusible PVC (DR21)	HDPE (DR 13.5)
Inside Diameter	36 in.	34.43 in.	35.405 in
Outside Diameter	37 in.	38.30 in	42 in.
Pipe Wall Thickness	0.5 in.	1.82 in.	3.11 in.
Pipe Joints	Weld	Fusion Weld	Fusion Weld
Yield Stress	40,000 psi	7,000 psi	3,500 psi
Modulus	29,000,000 psi	400,000 psi	Short Term 110,000 psi 50 Years 28,200 psi
Minimum Laydown Bend Radius	2,000 ft	800 ft	100 ft
Recommended Minimum Bend Radius in Bore	3,000 - 3,600 ft	1,000 ft	500 - 1,000 ft
Weight	588 lbs./ft	135.5 lbs./ft	166.88 lbs./ft
Pressure Rating	> 500 psi	200 psi	130 psi
Corrosion Protection	Polyurethane Lining	Not Needed	Not Needed
Standards	AWWA C200 ASTM A 1018	AWWA C905 ASTM D2241	AWWA C906 ASTM D3350 ASTM F714

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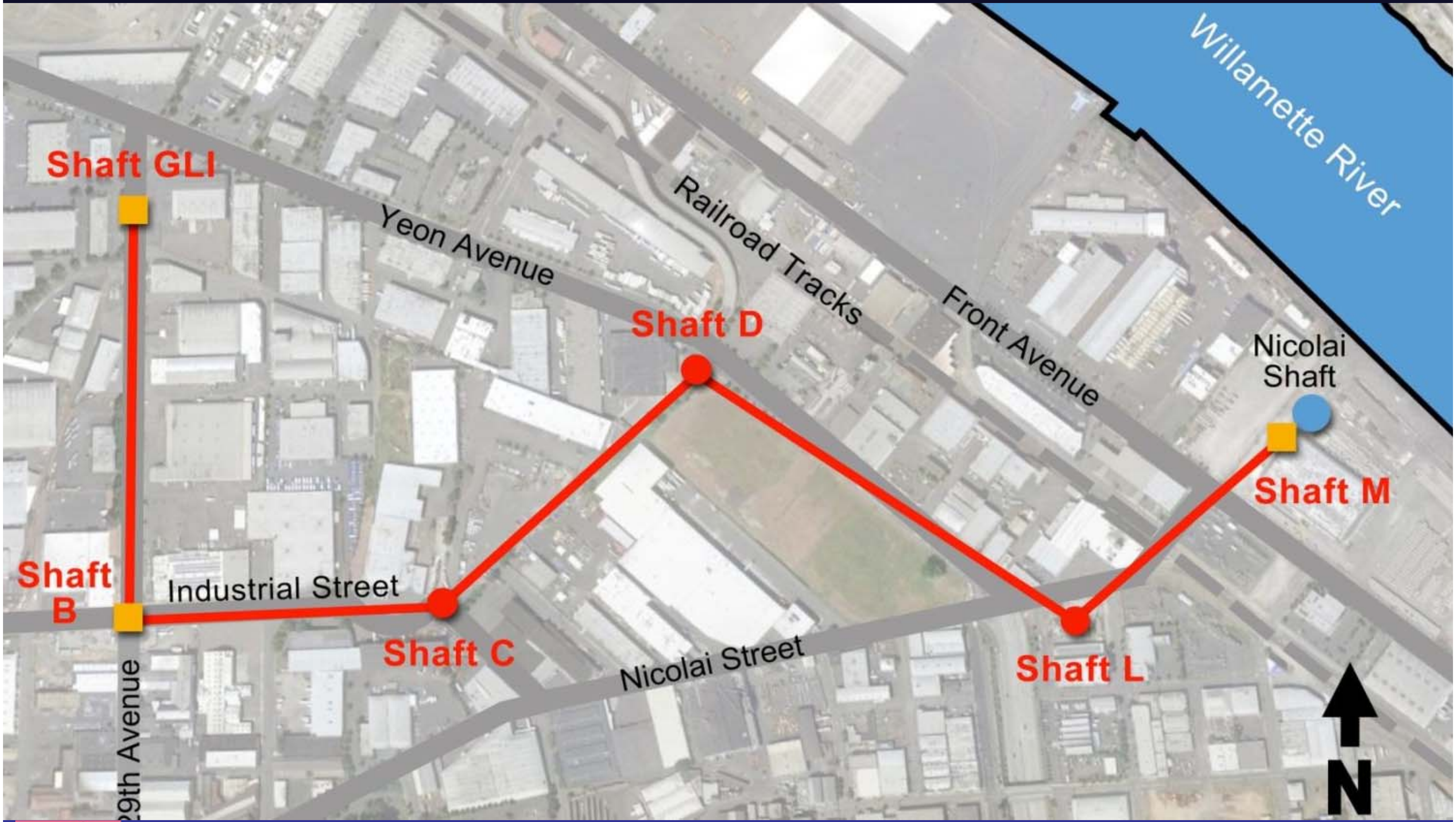
Typical Microtunneling Layout



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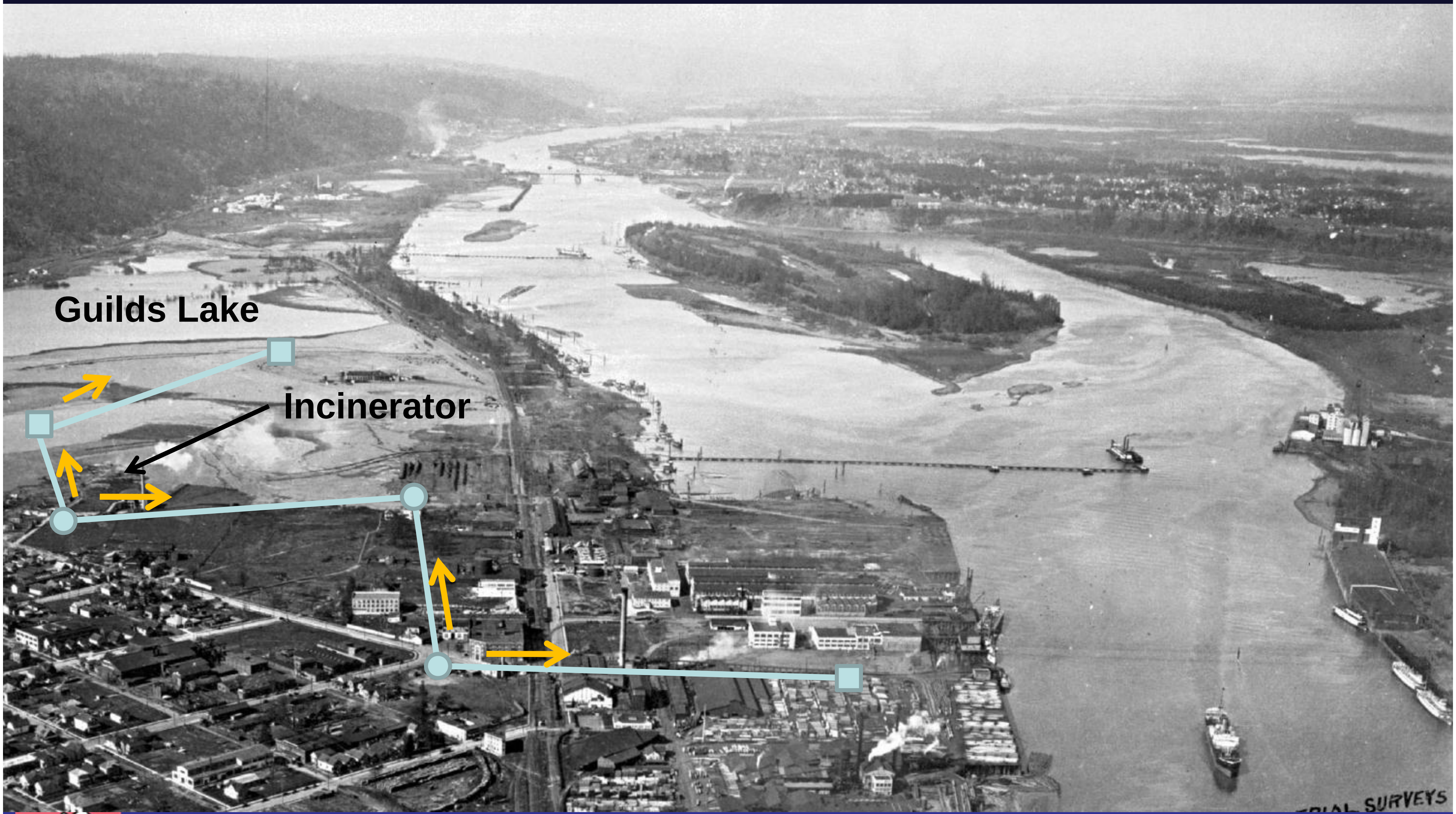
Site History



Staging Area Considerations

- Adequate space for staging and construction equipment
- Access
- Existing utilities (underground and overhead)
- Ability to reroute traffic
- Construction impacts (noise, dust, vibration)
- Angle points

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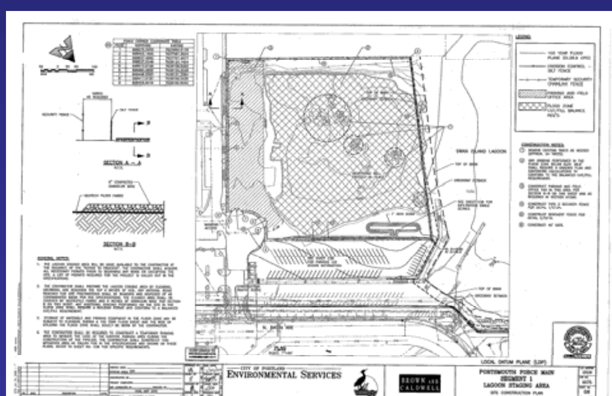
Shaft Considerations

- Jacking or Receiving (Rescue)
- Circular or Rectangular
- Frames, utilities, stairs, vents
- Pipe, segments, initial support
- Thrust blocks and seals
- Spoil handling, rail, supplies
- Ancillary equipment - pumps

Other Staging Area Considerations

- Alternative storage
- Mud disposal site
- Groundwater disposal options
- Alternative access
- Contractor flexibility
- Future project considerations
  - (paving, demolition)



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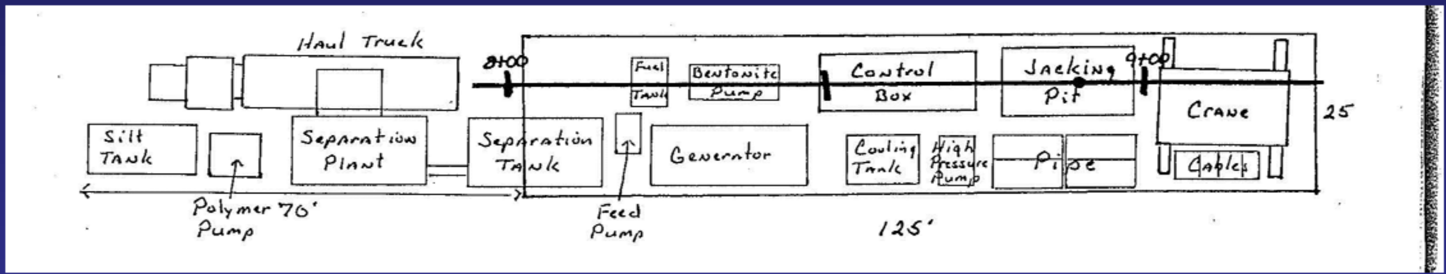
Creative Access and Staging



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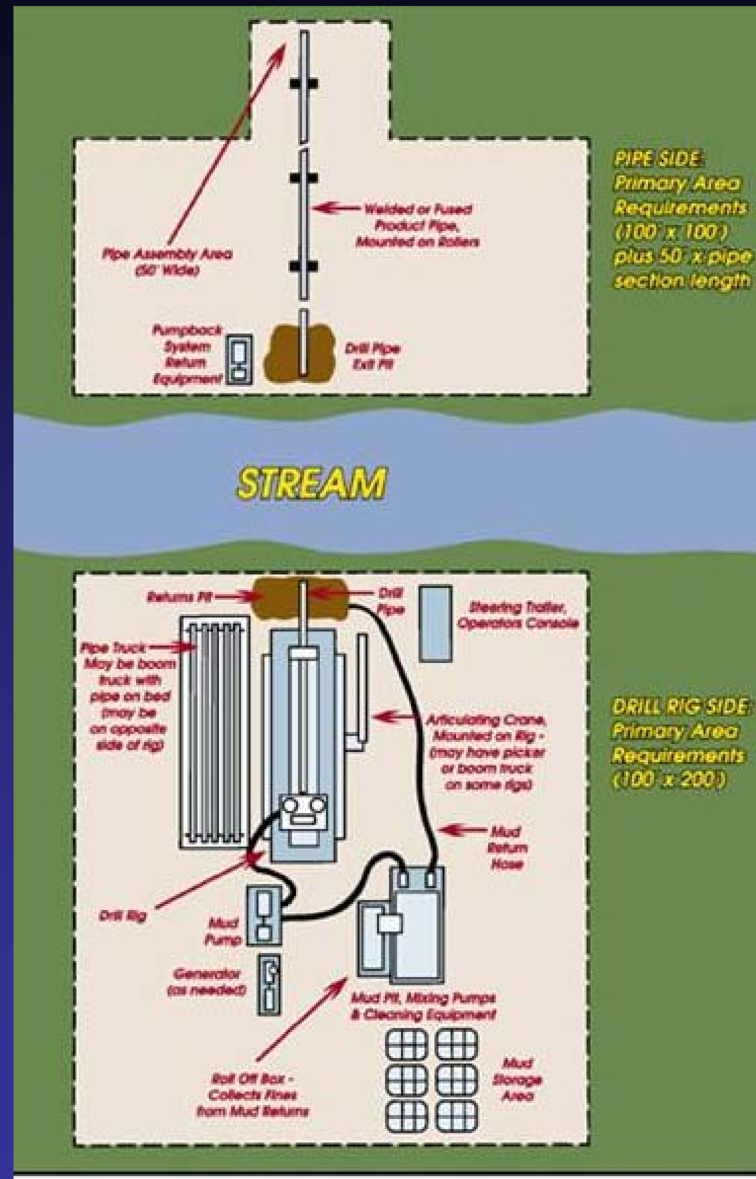
Typical HDD Layout



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Typical Urban Site Drill Set-Ups

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Pipeline Layout – First Tasks

Road Crossing
Pipeline Laydown Area

Other Pipe Handling Methods

Typical Laydown

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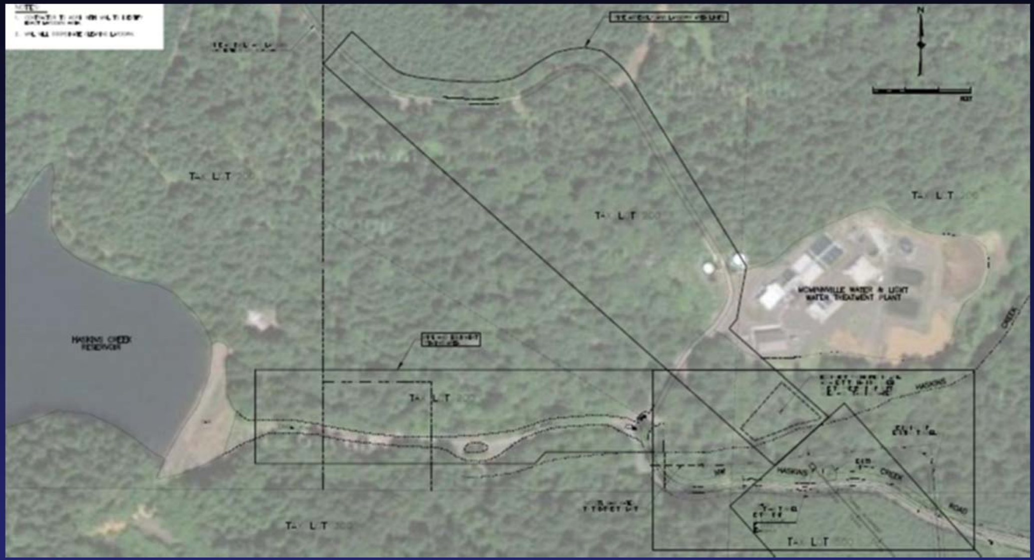
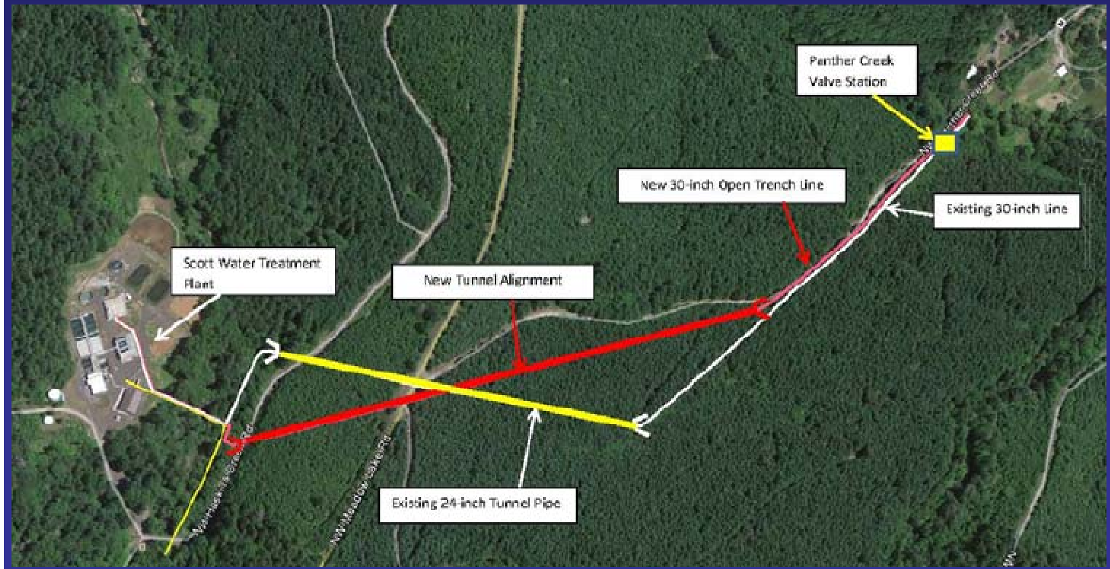
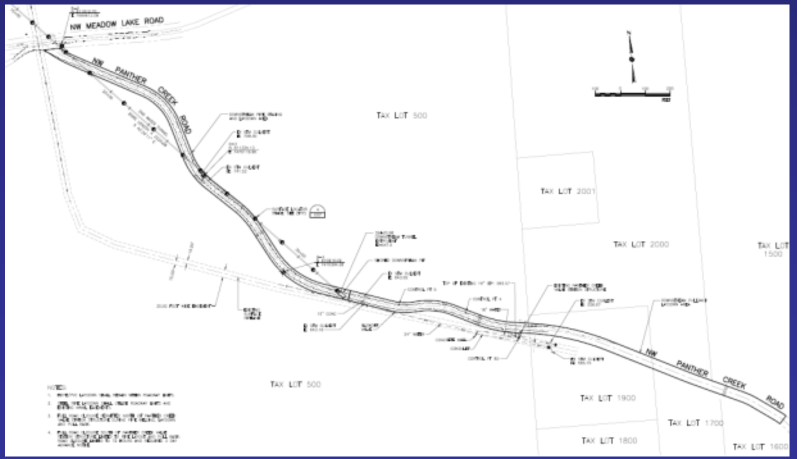
Pull Back Constraints - Example







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Identify critical project constraints and address community impacts

- Proof of concept staging layouts
- Noise and Vibration
- Pipe pullback assembly
- Access

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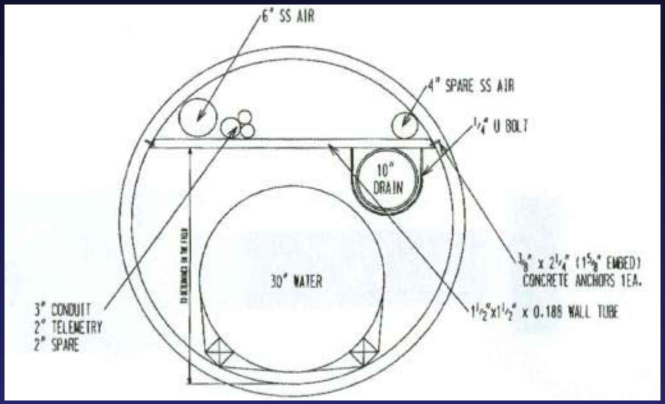
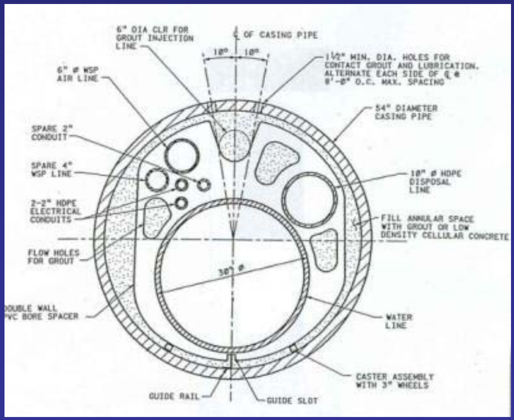
Key Design Issues

- Pipe Backfill
- Shafts
- Drive length
- Thrust
- Shaft base
- Shaft seals
- Ground support

Pipe Backfill

- Buoyancy
  - Lift Control
  - Grout Density
- Corrosion Protection





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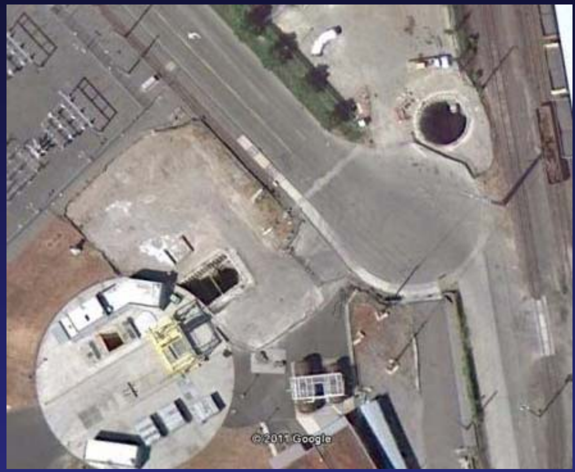
Construction Difficulty Often Occurs at Shafts

- Understand local experience
- Positive groundwater control
- Support methods compatible with geotechnical conditions
  - Intended use
  - Shape and size
  - Design Loads
  - Bottom heave, excavation stability
  - Launch and entry requirements
  - Initial vs. permanent



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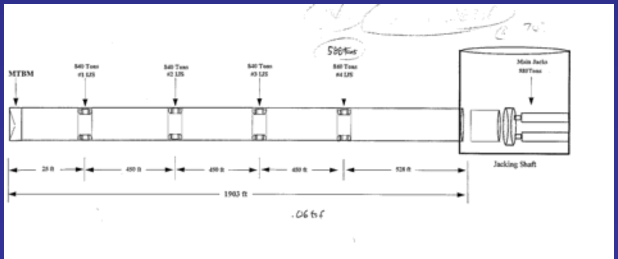
Shaft Excavation Support Systems

TYPE	SIZE AND SHAPE	DEPTH	GROUND TYPE	WATERTIGHT	REMARKS
Trench boxes and speed slide rails	Any size (width only limited by internal bracing)	20 ft	Most soils	No	Used above groundwater; short installation time
Soldier Piles and wood lagging (or steel plates)	Any size (width only limited by internal bracing)	60 ft	Any	No	Used above groundwater or with dewatering; limited cantilever depth; sequential excavation and lagging installation
Soil Nailing	Generally non-circular	50 to 60 ft	Most soils	No	Typically used above groundwater; requires specialized equipment; sequential excavation, used for portals
Liner plates	Any size (up to 30 ft dia.)	100 ft	Soil with stand-up time	No	Flexible; adaptive to various sizes; can be expensive
Conventional excavation with rock dowels and shotcrete	Any size (+/- 25 ft dia.- deep) (+/- 40 ft dia- shallow)	1000+ ft (deep), 200 ft (shallow)	Rock	No	Used in constructing mine shafts
Sheet piles	Any size (width only limited by internal bracing)	50 ft	Most soils (but trouble in cobbles and boulders)	**Yes**	Can be reused; inexpensive; used below groundwater; limited by crossing utilities; pre-drilling required in rock or bouldery ground
Secant piles	Circular (+/- 35 ft diameter)	110 ft	Most soils and weak rock	**Yes**	High cost; requires specialized equipment; limited by crossing utilities
Drilled shafts	Circular (+/- 30 ft diameter)	200 ft	Most soils and weak rock	**Yes**	High cost; requires specialized equipment; limited by crossing utilities
Cutter soil mixing	Any size (+/- 35 ft diameter)	90 ft	All soils	**Yes**	Similar to slurry walls; specialized equipment; generates heat with cement
Slurry walls	Any size (+/- 135 ft diameter)	200 ft	All soils	**Yes**	Specialized equipment; expensive; limited by crossing utilities
Ground freezing	Any size (+/- 35 ft diameter)	200 ft	Most soils	**Yes**	Difficult to freeze moving water or saline-rich water; high energy costs; allows flexible layouts and shapes
Caissons	Any size (+/- 30 ft diameter)	130 ft	Most soils	**Yes**	Typically part of the permanent works; can be used below water table; limited by crossing utilities

Long Drives Eliminate Shafts

- Jacking Forces
- Mechanical Constraints
- Guidance Issues

Project	Pipe Size	Drive Lengths (feet)	Project Highlights
Portsmouth Force Main	81-inch ID Steel	1,900	Record for the longest U.S. drive using a jacked steel casing
Balch Consolidation Conduit	84-inch ID RCP	1595, 1,670	Longest microtunneling drive in gravel. ACEC Grand Project Award 2011
ESCSO	84-inch ID RCP	3,055	Longest microtunneling drive in North America
Tanner Creek	72-inch ID RCP	1,000	First use of slurry microtunneling in Portland



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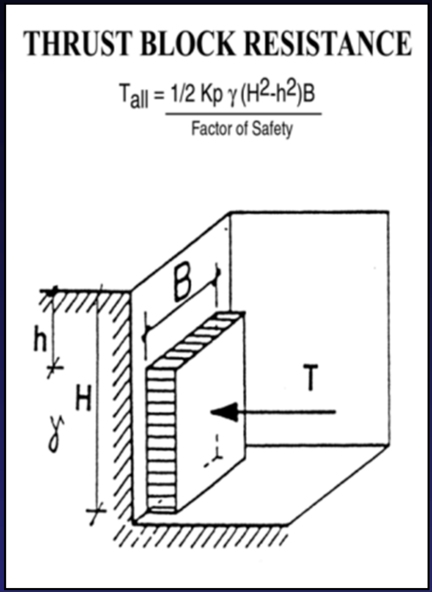
Thrust Restraint

- Can limit drive length if soils are weak
- Transfer load to soil without excessive deformations
- Prevent cracking of rigid walls
- Improve soils to control deformations, if necessary
- Construct perpendicular to pipe alignment



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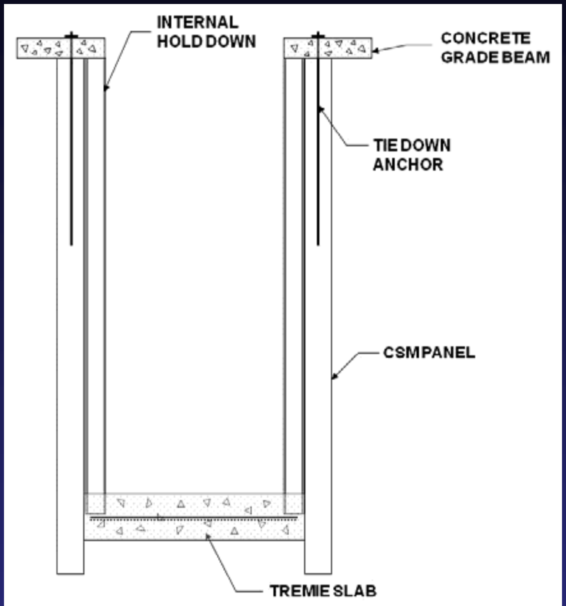
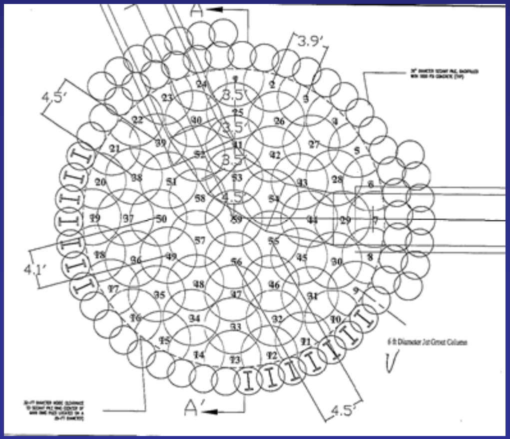
Shaft Base





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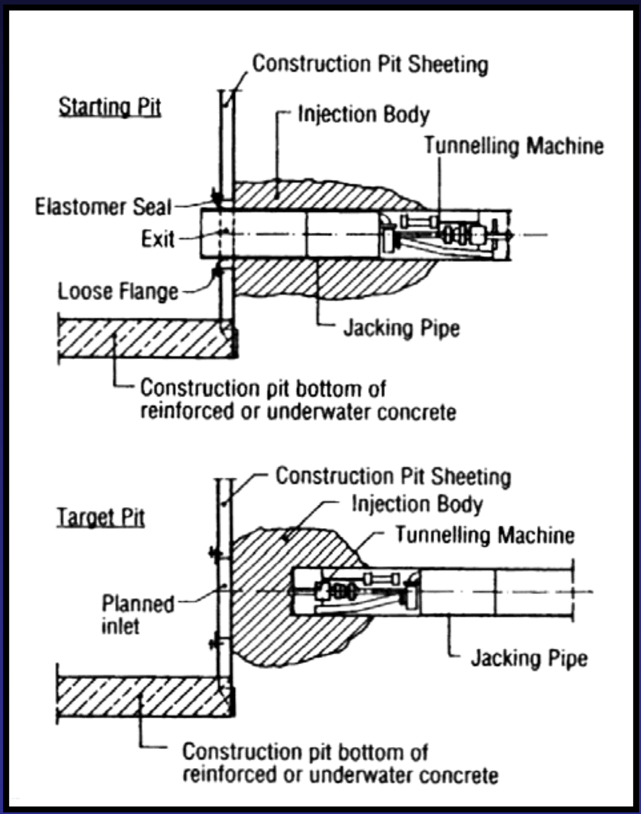
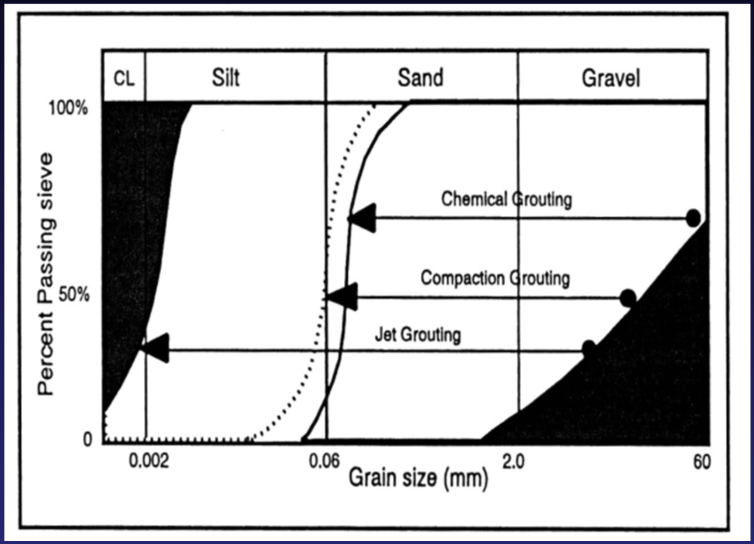
Shaft Entrance and Exit





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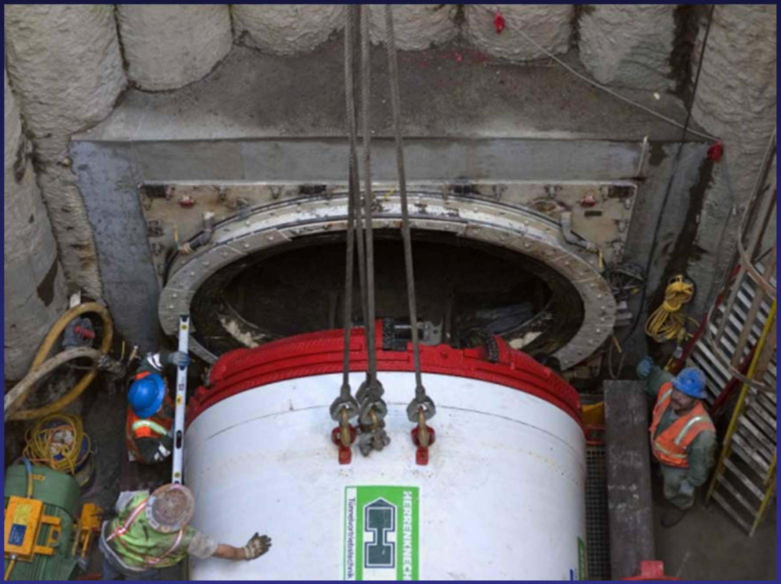
Shaft Seals



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Pipe Brake

Jacking force calculations need to include pipe brake calculations. How much force to push the pipe into the ground and how much resistance is there to resist the face pressure and backward movement of the pipe during pipe changes.

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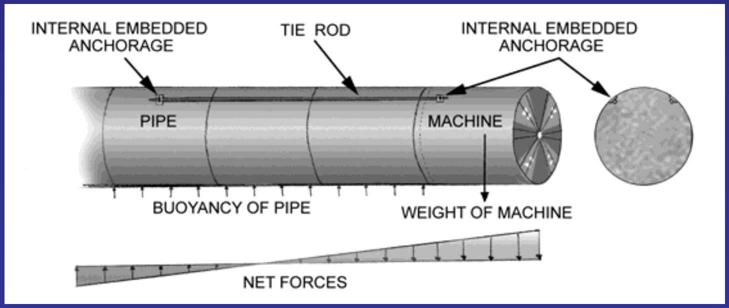
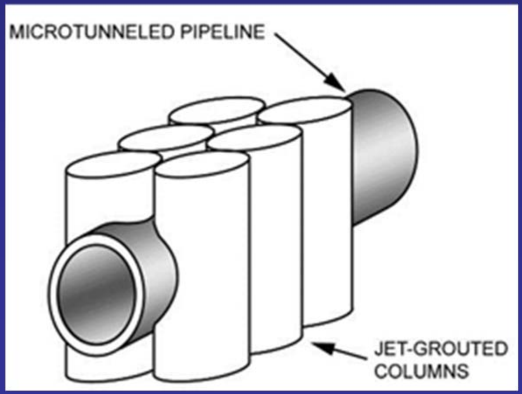
Low Blow Count Soils

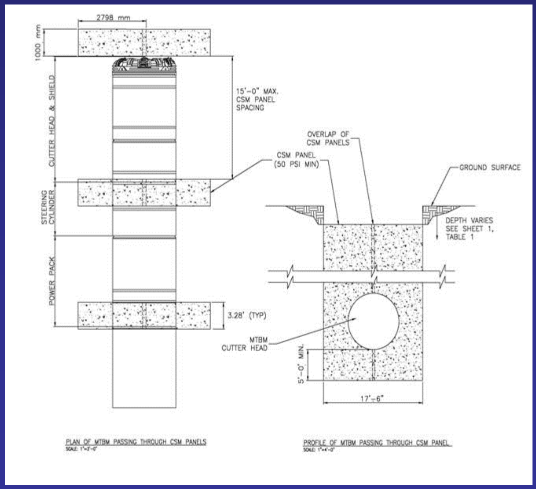
- Prone to settlement
- Easy to over excavate
- Diving of the machine
- Loss of grade control
- Insufficient steering resistance
- Pipe flotation

Material	Jacking Pipe Outer Diameter			
	30 in. (760 mm)		60 in. (1,525 mm)	
	Wall Thickness, in. (mm)	Weight, lb/ft (kg/m)	Wall Thickness, in. (mm)	Weight, lb/ft (kg/m)
Steel [1]	0.375 (10)	119 (177)	0.75 (19)	475 (707)
CCFMP [2]	1.53 (39)	137 (204)	2.13 (54)	380 (565)
Polymer Concrete	2.8 (71)	234 (348)	5.375 [3] (136)	869 [3] (1,293)
Vitrified Clay	3.2 (81)	251 (373)	[4]	[4]
RCP "C" wall	3.75 (95)	365 (543)	5.75 (146)	1,010 (1,503)

[1] Permalok™
[2] Hobas™
[3] 58 in. (1,473 mm) OD
[4] Pipe size not available







CASE HISTORY

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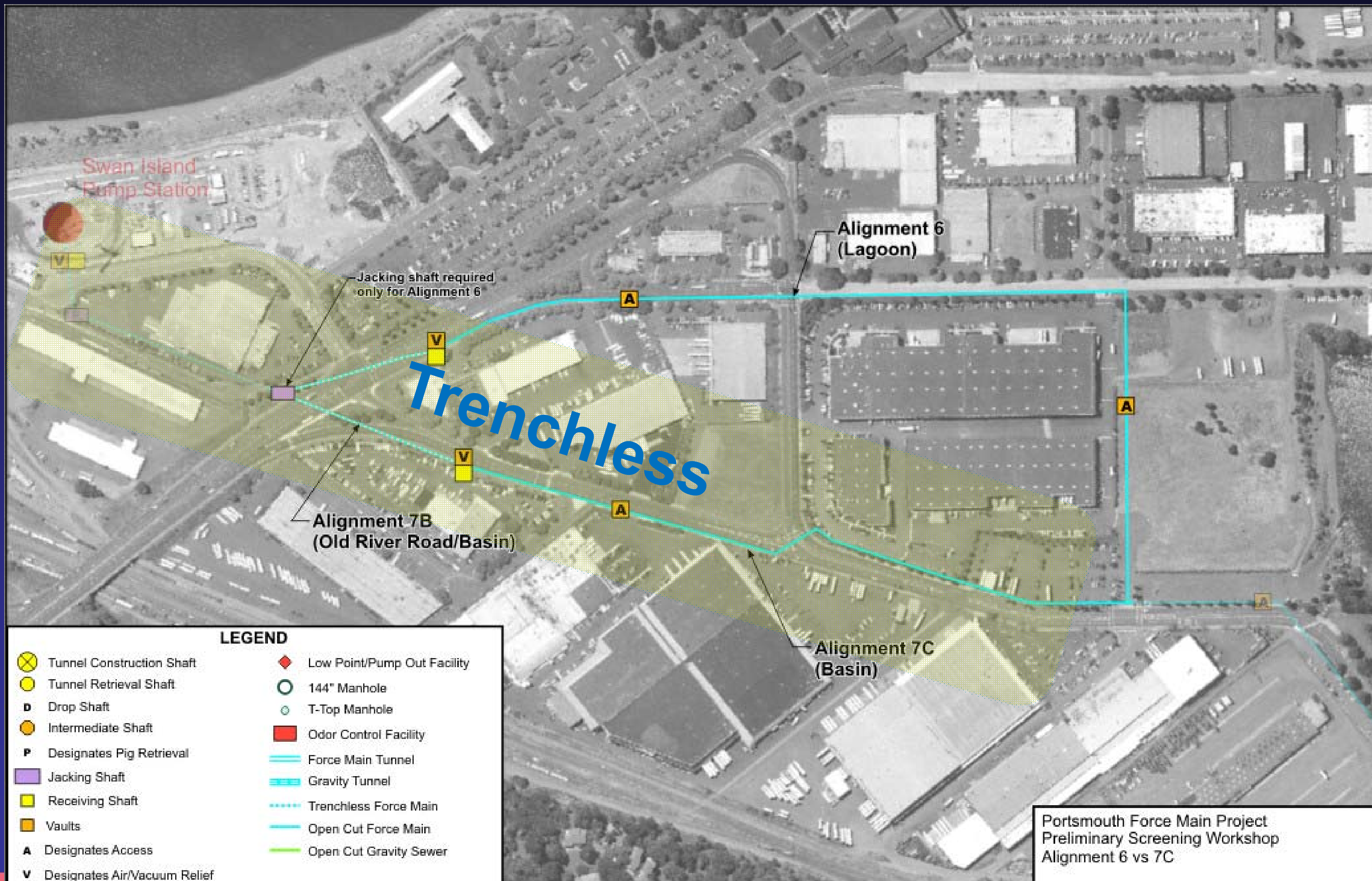
Shaft Considerations in Alignment Evaluation



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Project Layout

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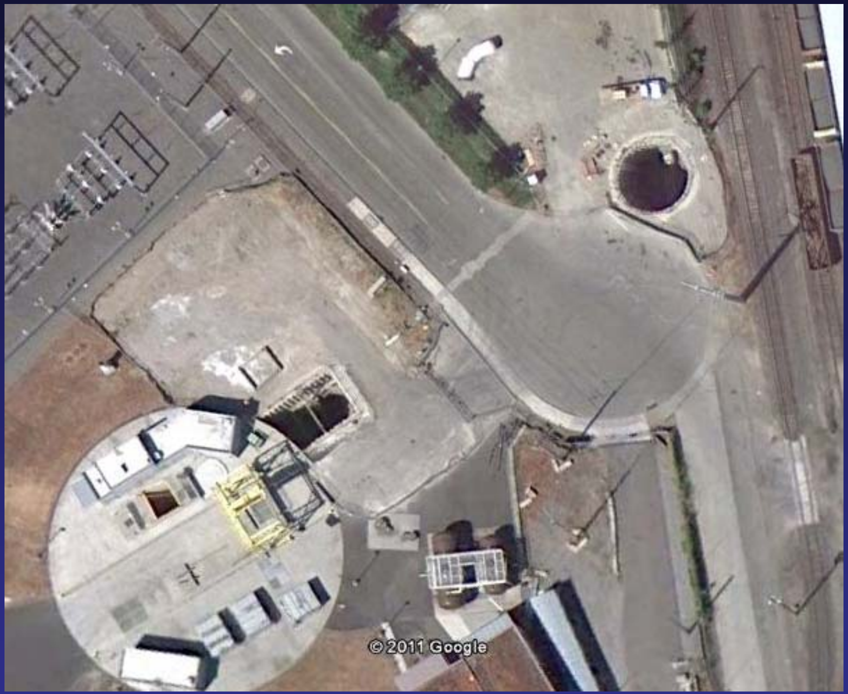
SIPS Shaft

- Key Constraints
  - Next to river
  - Known obstructions (flour mill)
  - Shared worksite
  - Build-out by others
- Owner designed shaft
- Attached to existing structure



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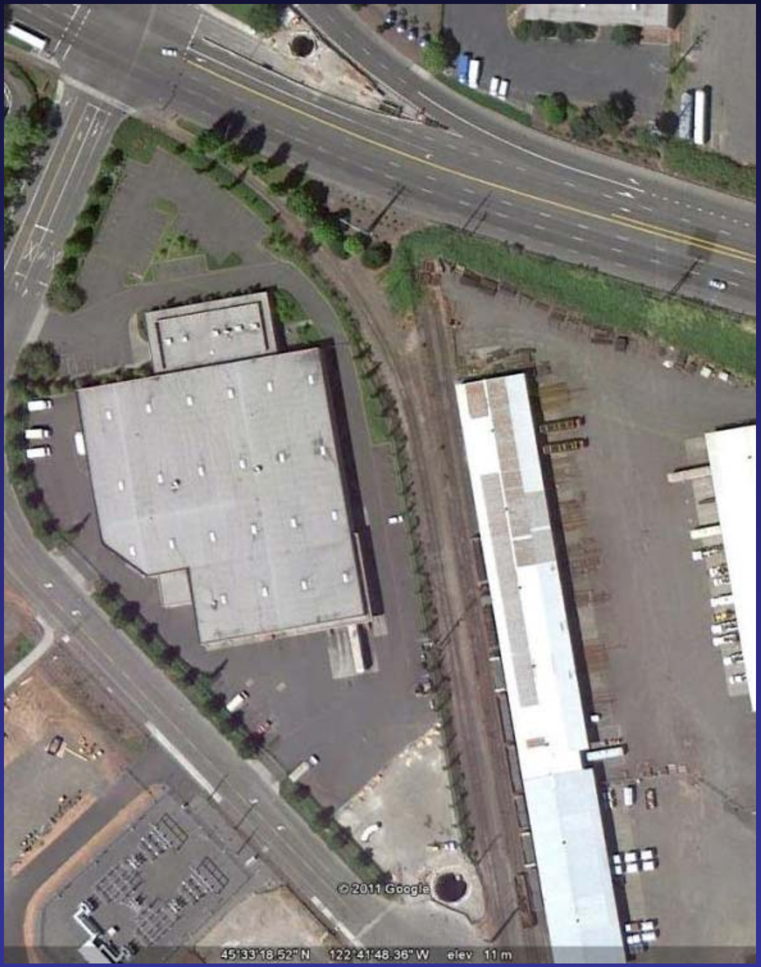
Port Center Way Shaft

- Similar constraint as SIPS
  - Located in FedEx property
  - Entrance to Rail Yard
  - High Voltage Power lines to Pump Station
- Secant Pile shaft with base seal
- Optional Shapes



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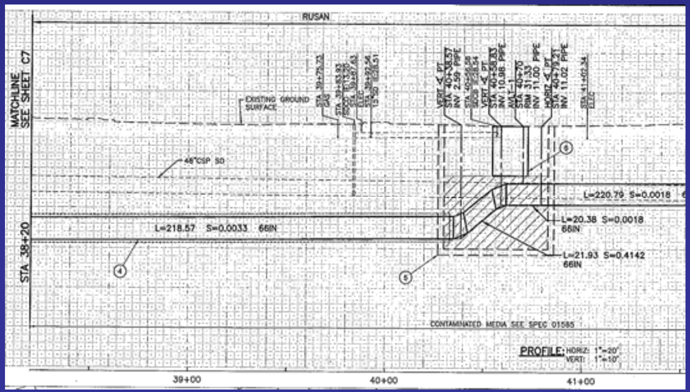
Shaft Location

- Jacking Shaft
- Key constraints
  - Construction Access
  - Business Impacts
  - Old shoreline
  - Profile transition
- Location flexible



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Going Street Shaft

- Key constraints
  - Traffic (main island access)
  - Utilities
  - Construction access
- Contractor designed (flexibility)
- Receiving shaft only
- Traffic control design

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Available Standards

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Concluding Thoughts

- New microtunneling standards coming out
  - Line and grade tolerances are 3% of MTBM diameter for grade and 6% of MTBM diameter for line.
- Hybrid methods are becoming more available
- Consider larger machines in challenging soils
- Min. size for access is 48-inches
- Contingency planning
- Use proven, local shaft construction methods
- 8” to 24” is a good HDD size to maintain flexibility in design an minimal laydown requirements (rig sizes and pipe flexibility)
- Larger diameters and longer HDD bores start to exponentially increase impacts and engineering efforts

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- Public unveil of the Microtunneling Standard at a workshop at the ASCE Pipelines conference in Portland, on Sunday, August 3 from 1 pm to 5 pm.
- HDD workshop in the morning, same day to present the changes made to MOP 108, the manual of practice on HDD.

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Questions & Answers

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