ICTIS

Horizontal Directional Drilling (HDD) Guidelines and Challenges

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Outline

- HDD Introduction
- Design Issues and Guidelines
- Challenges and Risks
- Conclusions

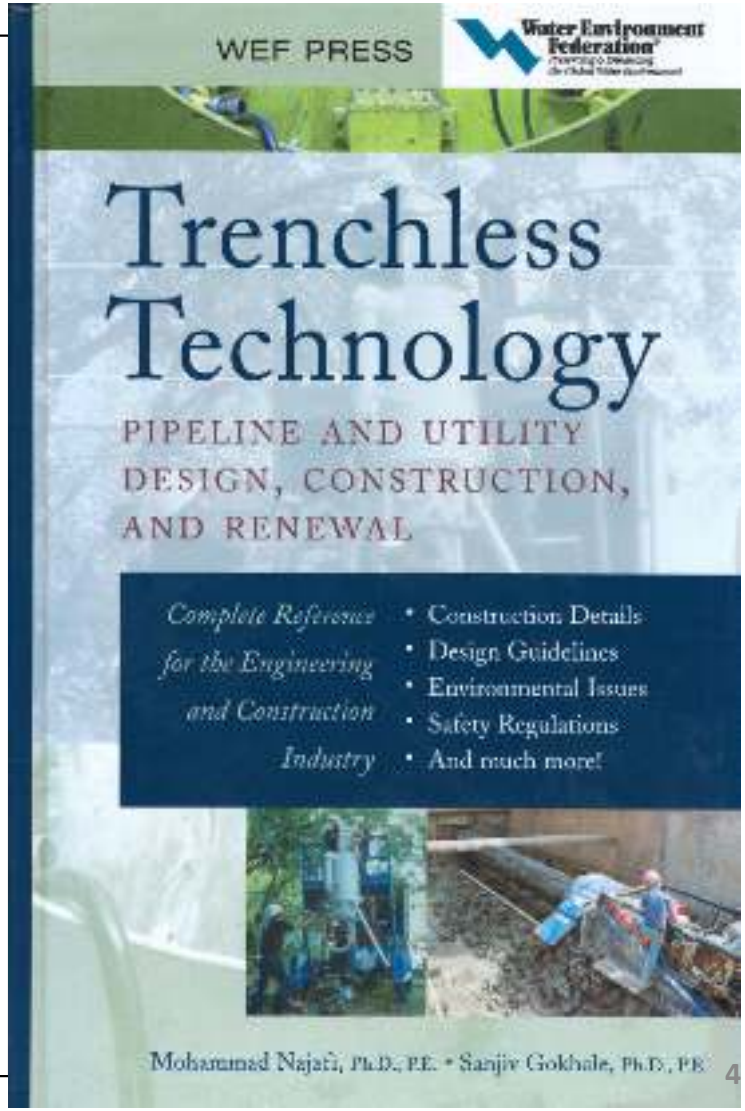
Center for Underground Infrastructure Research & Education

Grouping of university, municipal, industrial, business and governmental representatives committed to the advancement of knowledge in materials, methods and equipment used in underground infrastructure.

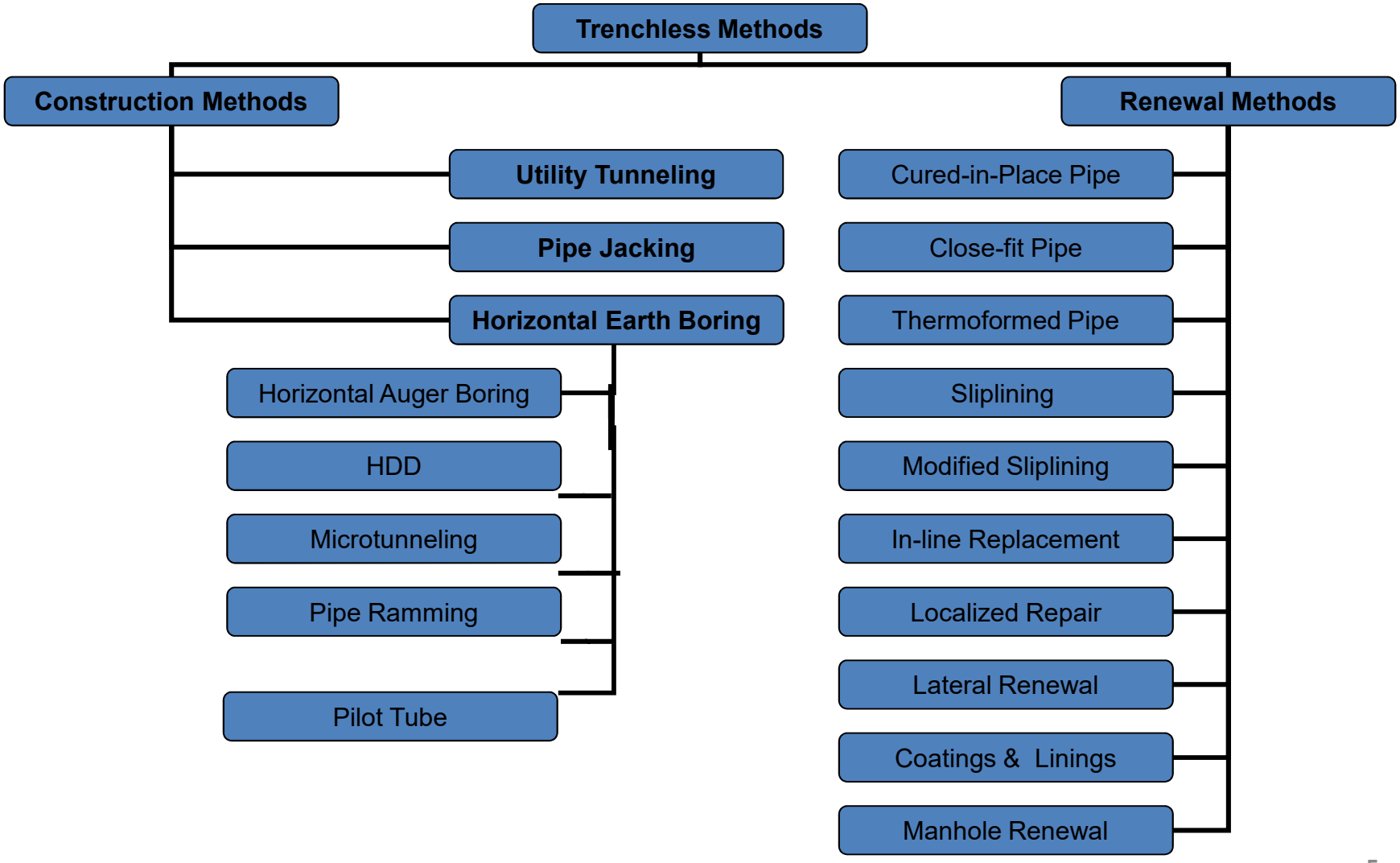
Trenchless Technology Methods

Trenchless Technology:

All methods of pipeline and utility installation and renewal with minimum disruption of surface and subsurface



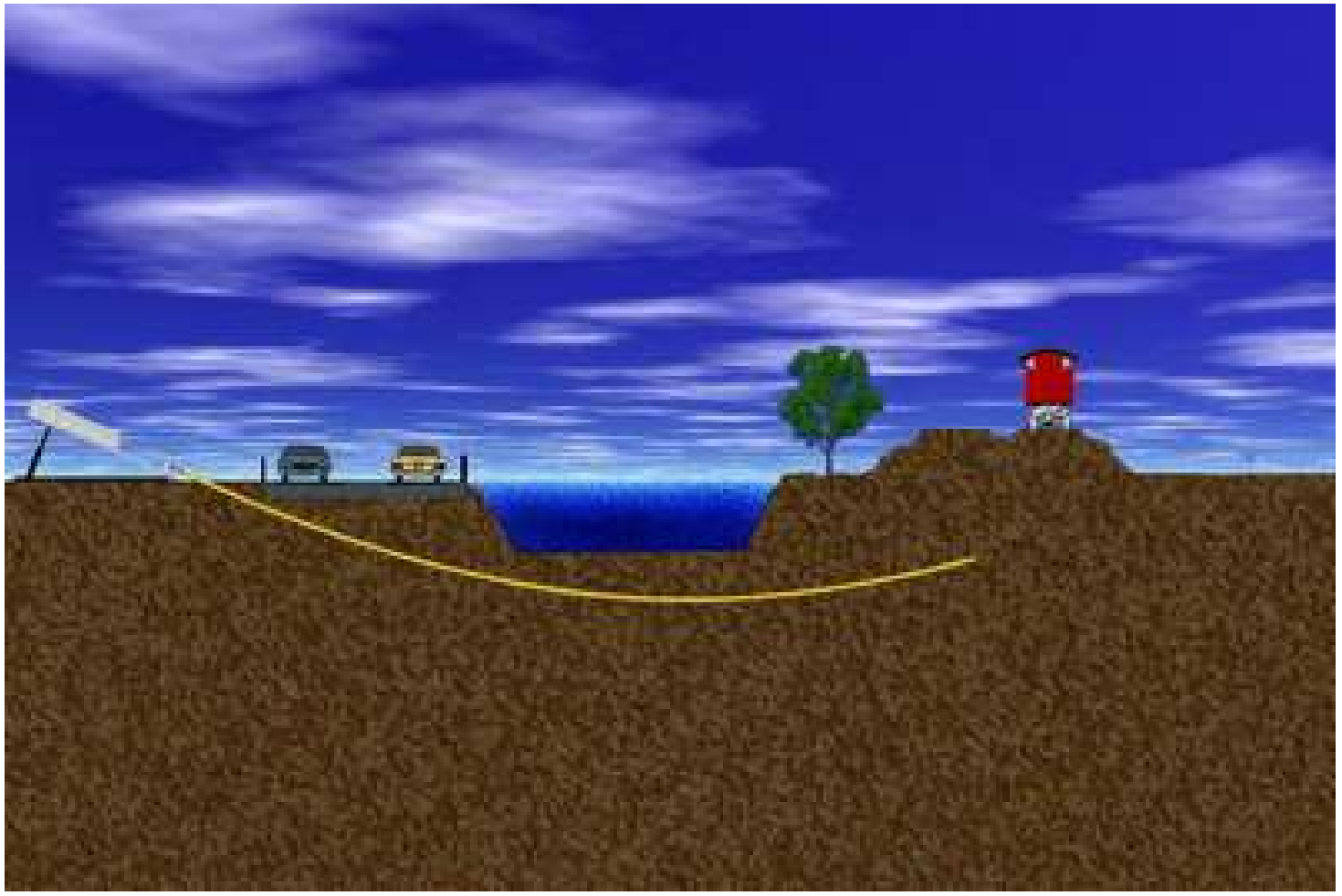
Trenchless Technology Methods

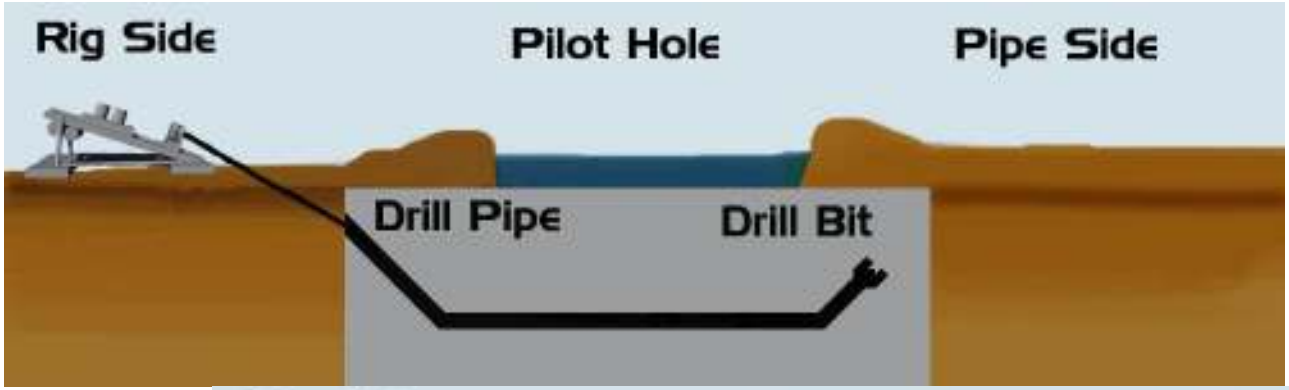


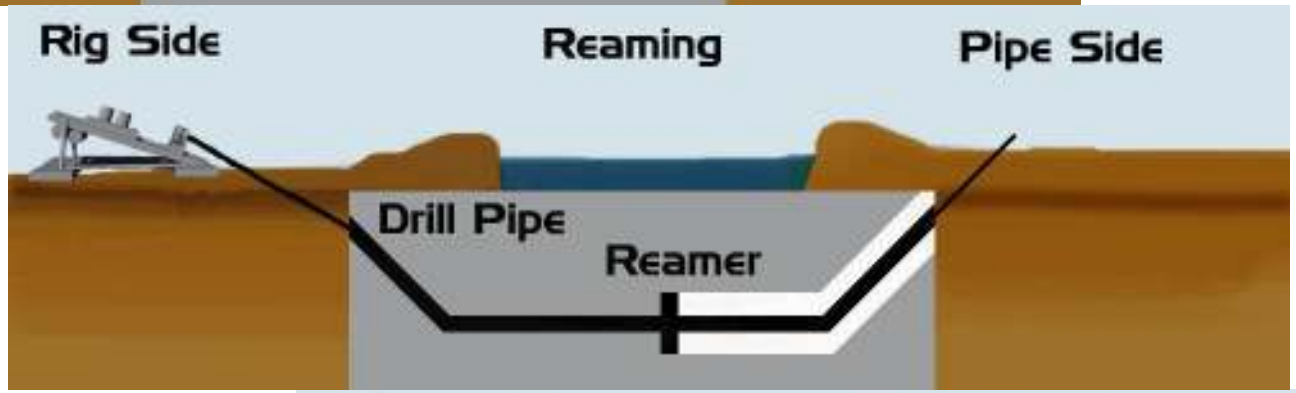
Horizontal Directional Drilling Method (HDD)

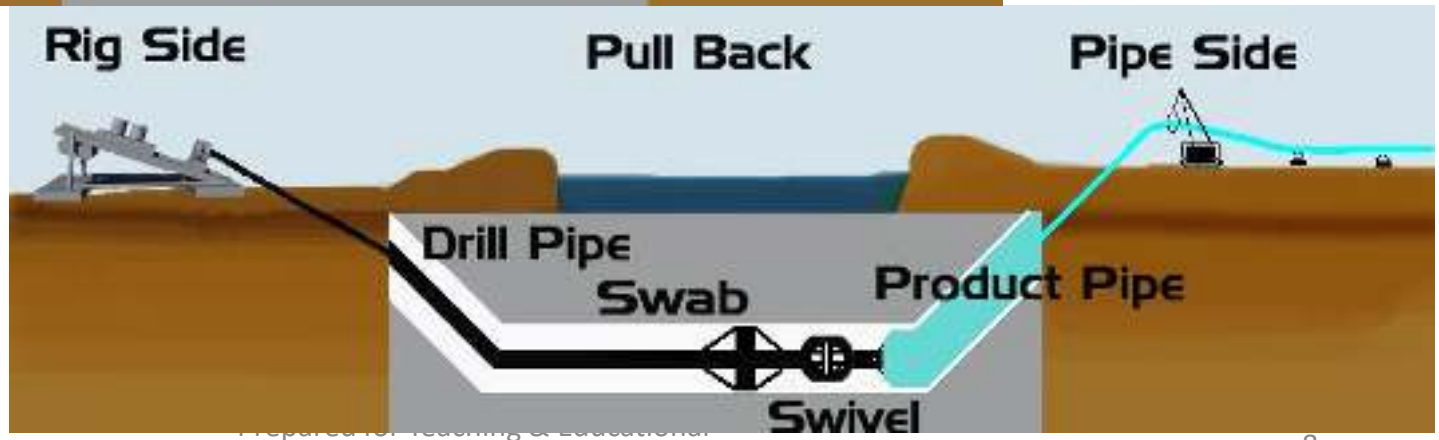
- Horizontal Directional Drilling (HDD)
  - Performed in two *or more* steps
    - Drilling of pilot hole using a steerable drill head & guidance system
    - Back-reaming to increase pilot hole diameter & pullback of product pipe
  - Product pipe sizes up to about 60”
  - Typically used for pressure pipes

Horizontal Directional Drilling (HDD)









Horizontal Directional Drilling Method (HDD)

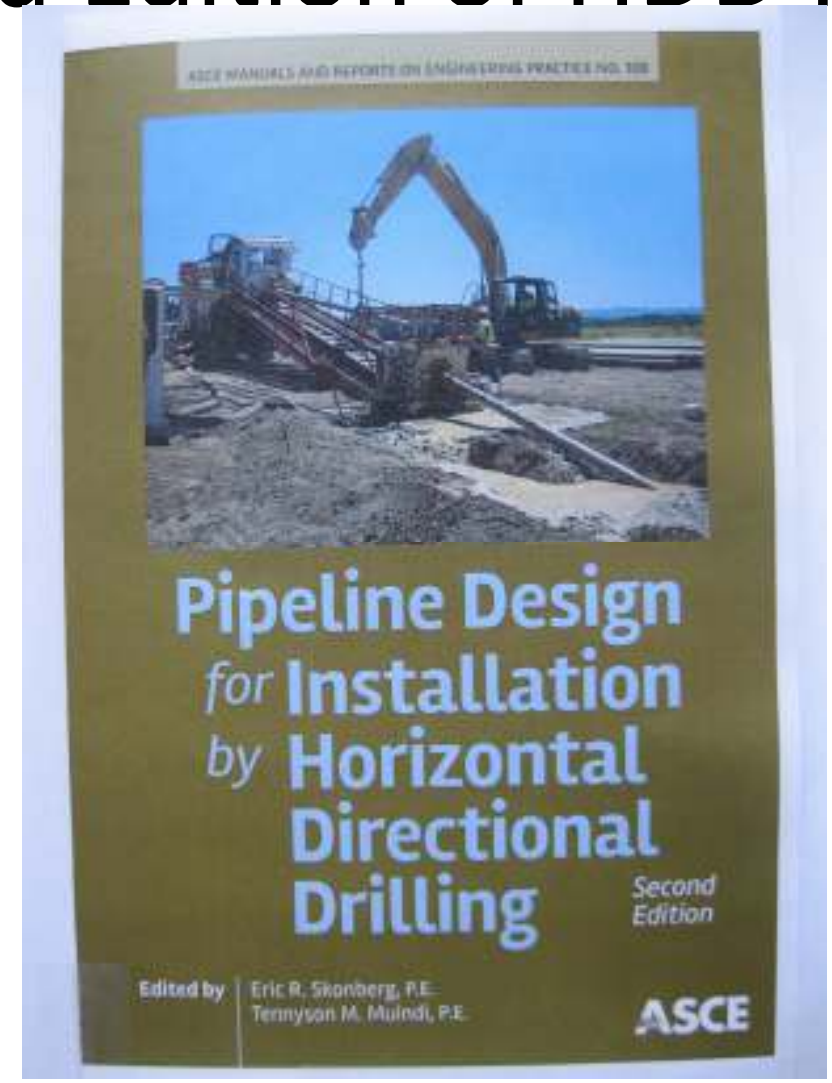
Characteristics of Horizontal Directional Drilling

Method	Diameter Range (inches)	Maximum Installation (feet)	Pipe Materials	Typical Applications	Accuracy (+ or -)
Mini-HDD	4”-12”	< 600’	PE, Steel, PVC	Pressure Pipe & Cables	Varies
Midi-HDD	12”-24”	600’ – 2,000’	PE, Steel, DIP	Pressure Pipe	Varies
Maxi-HDD	24- 60”	2,000’ - 12,000’	PE, Steel	Pressure Pipe	Varies

Current State-of-the-Art

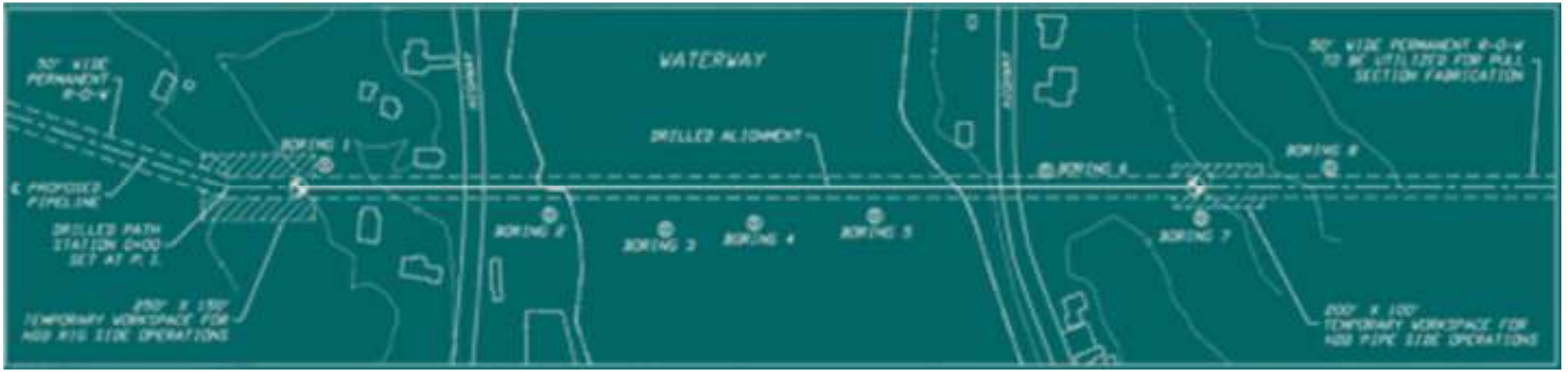
- Pilot holes have been drilled to lengths of more than 12,000 feet (drilled intersect technique)
- Pipe diameters up to 18 inches have been installed over lengths of more than 12,000 feet
- Pipe diameters up to 36 inches have been installed over lengths of more than 9,000 feet
- Pipe diameters up to 42 inches have been installed over lengths of more than 7,000 feet
- Steel pipe diameters up to 56 inches and HDPE diameters up to 65 inches have been installed successfully
- Pipe diameters up to 42 inches are fairly common

Second Edition of HDD MOP 108



Surface Surveys

- Visit the sites to investigate available work space
- Survey along proposed HDD alignment for a width of 100-ft.
  - Determine existing grade
  - Denote roads, buildings, utility lines
  - Wetlands



Subsurface Survey

- Utility Research
- Geotechnical Investigation
- Hazardous Material Investigation

Subsurface Survey – Additional resources

- Historical maps
- Historical photographs
- Aerial and space photographs
- Previous studies

Utility Research

- Utility Research – look for exiting utilities
  (refer to CI/ASCE 38.02 (ASCE 2002)

- ASME B31.4-2009 requires the crossing plan & profile to include all “pipelines, utilities, cables & structures” be identified within 100-ft. of the drill path

Utility Research

- The best start….

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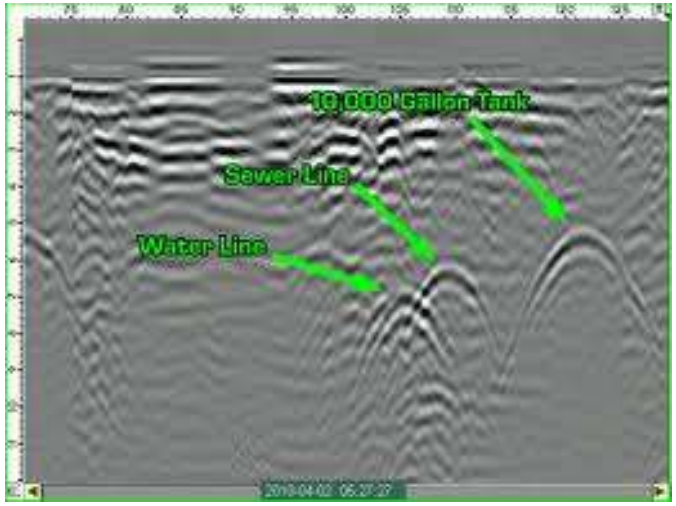
Utility Research

- Pipe Locators
- Usually Magnetic
- Generally less accurate with depth
- But very accurate to 12-ft.

Utility Research

- Ground Penetrating Radar (GPR)
- Interpretation is Critical
- Most useful at depths less than 20-ft.
- More effective in dry soils



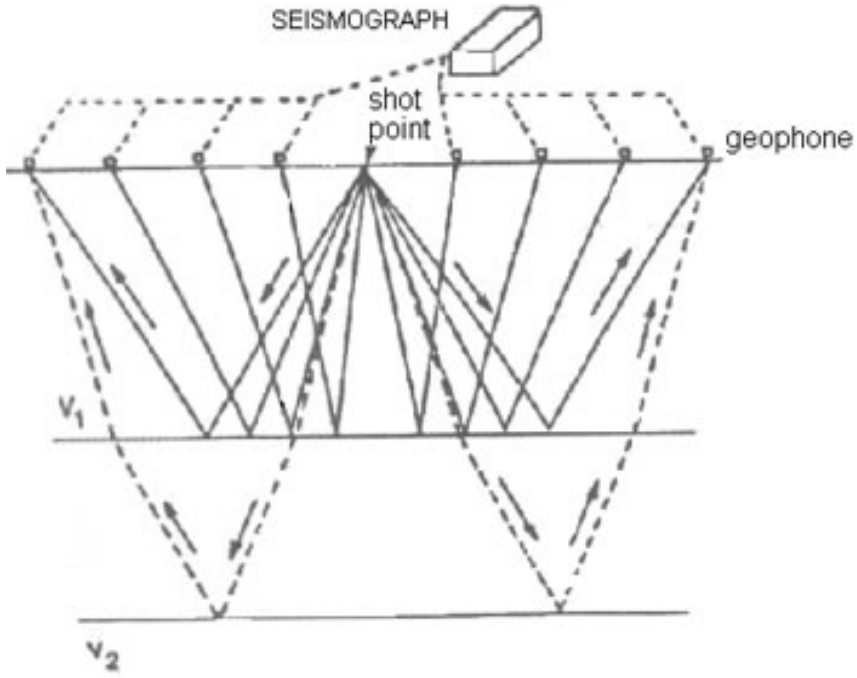
Utility Research

- Vacuum Excavation
- Reduces risk of damage to utilities
- Allows for physical ID
- Generally limited to 20-ft.

Utility Research

Seismic

- Records the time of the sound origin and time of arrival at detector
- Generally not used in congested areas
- Interpretation is key



SEISMIC REFLECTION

Geotechnical Investigation

- Tailored to suit the geotechnical complexity of the crossing route
- Should include a general geologic review and sampling
- Borings should be off the alignment and at least 20-ft. lower than the planned HDD profile
- Borings should be grouted upon completion
- Depth to watertable should be noted

Geotechnical Investigation

- Samples should be tested by a qualified laboratory for:

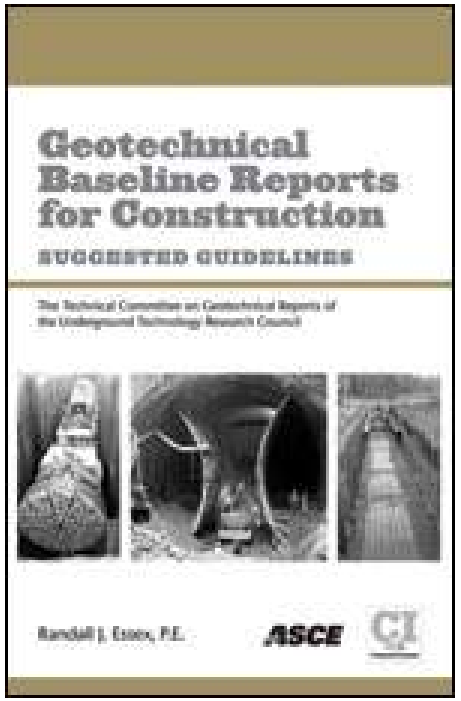
  - Standard Classification (ASTM D2487)
  - Gradation Curves for gravel
  - Standard Penetration Tests (SPT)
  - Description for rock
  - Mohs Hardness
  - Rock Quality Designation (RQD) (ASTM D6032
  - Unconfined Compressive Strength
  - Unit Weight
  - Atterberg Limits
  - Cohesion Coefficient
  - Soil Friction Angle

Geotechnical Investigation

- Should be presented in a report containing engineering analysis, boring logs, test results and a profile of subsurface conditions

- Experienced engineering judgment should be applied in evaluating and allocating risk

- Geotechnical Baseline Reports for Construction (GBR) is a risk management tool that is used to measure from where differences are measured and changes are evaluated

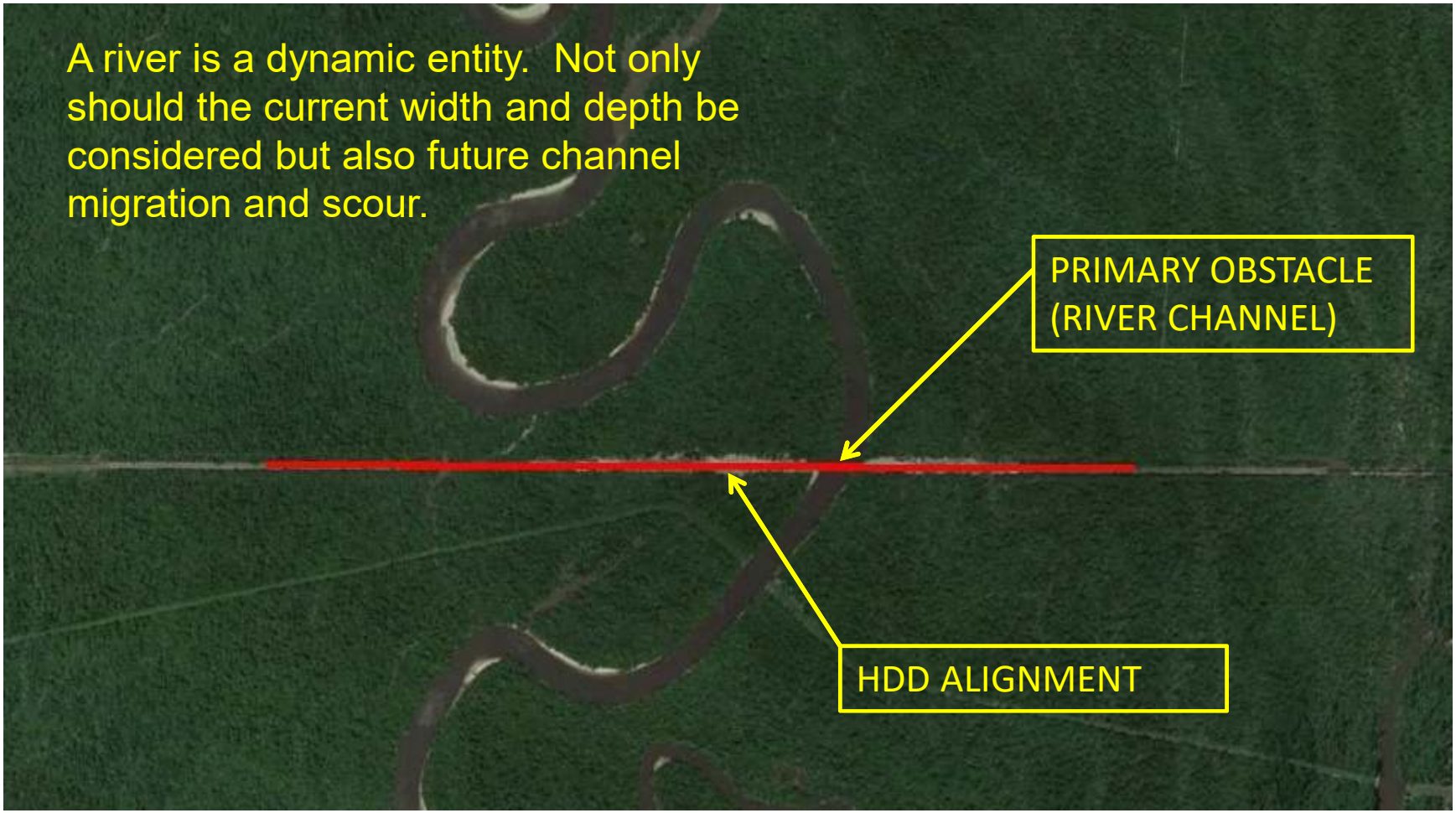


Hazardous Material Investigation

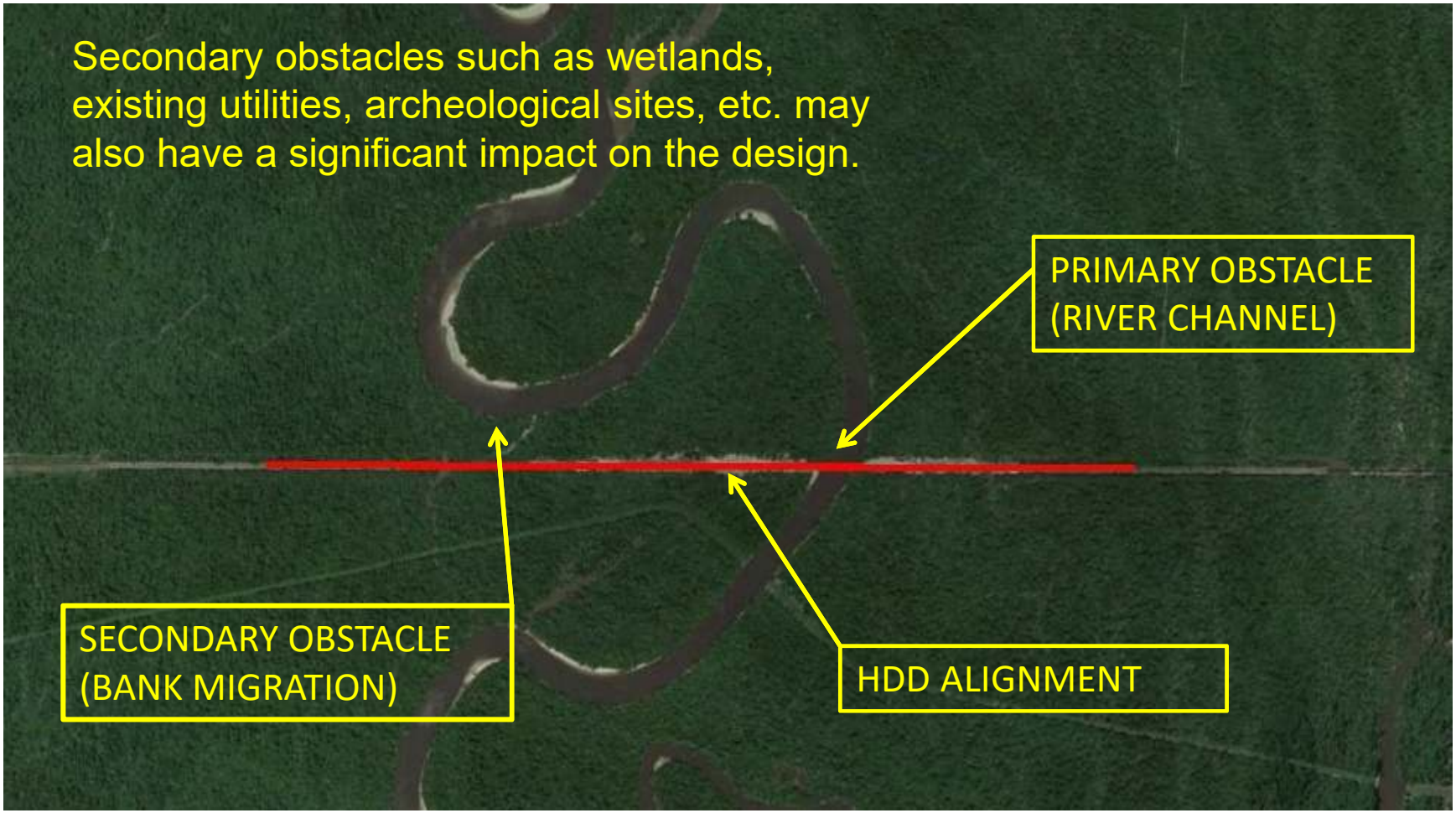
Naturally Occurring:

- Carbon Dioxide
- Low Oxygen
- Hydrogen Sulfide
- Petroleum
- Serpentine (rock) - Asbestos

HDD Alignment



HDD Alignment

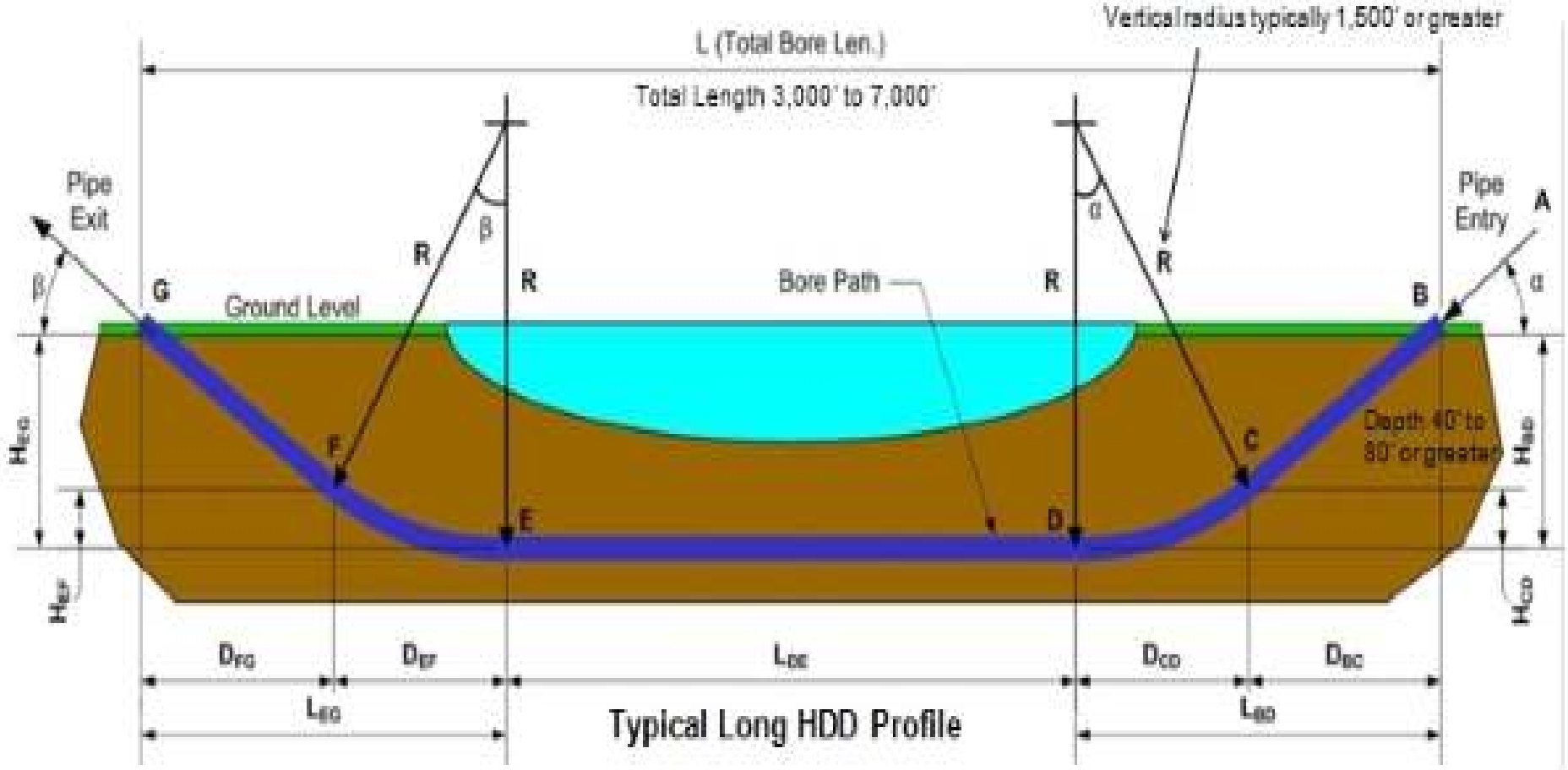


Exposed Pipeline – Bank Migration

General Design Considerations

- Minimize the drilled length. Reduces cost/risk.
- Lengths in excess of 13,000 feet have been accomplished using the **“intersect”** technique. However, with increased length comes increased risk of HDD operational problems and delays.
- Avoid subsurface conditions consisting of coarse granular material (gravel, cobbles, boulders) to the extent possible.
- Although horizontal side bends are feasible, minimize their use.

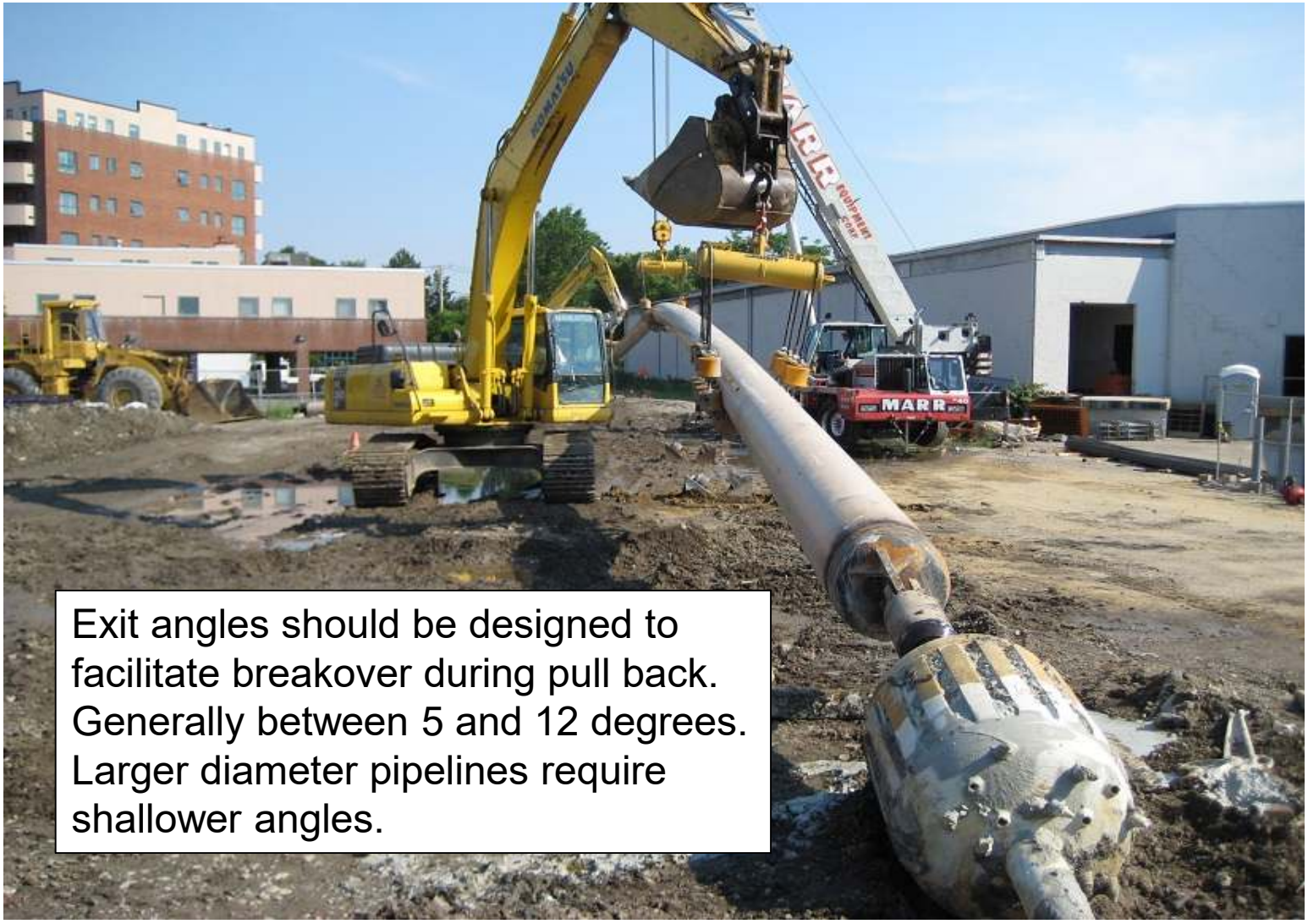
Design Terminology



Entry Angles

Entry angles should be held between 8 and 20 degrees with horizontal. Most HDD rigs are set to operate best between 10 and 12 degrees.

Exit Angles



Exit angles should be designed to facilitate breakover during pull back. Generally between 5 and 12 degrees. Larger diameter pipelines require shallower angles.

Pipe Handling - Steep Exit Angle

Radius of Curvature or Bending Radius

HDD Industry Practice:

Radius (feet) = 100* Diameter (inches)

- For example, the design radius for a 24-inch steel pipe would be 2,400 feet.
- “Rule of Thumb” has been developed over the years in the HDD Industry and is based on experience rather than analysis.
- Radius can be reduced from this standard in some cases. This is particularly true with HDPE.

Depth of Cover

- Typically, HDD crossings should be designed with a minimum of 25 feet of cover.
- Only in special cases should less than 15 feet of cover be provided.

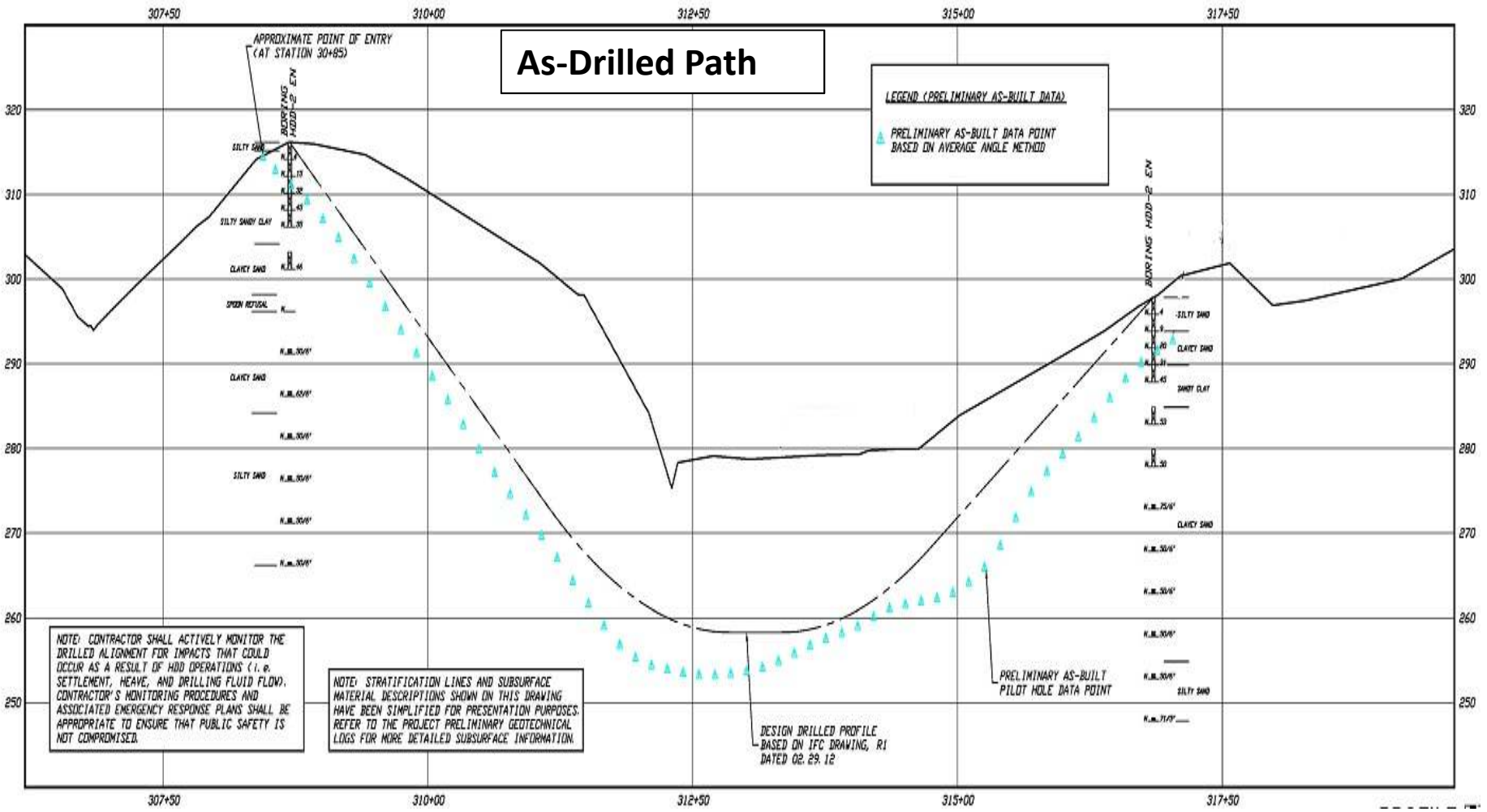
Reduced Cover – Higher Risk of Impact

Inadvertent Drilling Fluid Return “Frac-out”

Sink hole along the HDD alignment

In order to reduce impact in sensitive areas, 40 feet or more may be necessary to minimize risk of inadvertent drilling fluid returns or drilling fluid impact.

Directional Drilling Accuracy



Directional Drilling Accuracy

- The HDD pilot hole will not usually be constructed exactly on the design centerline.
- Line and grade tolerances may not be achievable or may require multiple pilot hole attempts.

Specify Pilot Hole Tolerances

- Acceptable deviations from the centerline (horizontal and vertical) must be specified (pilot hole tolerances).
- Typical tolerances: Plus or minus 10 feet in alignment, Plus 5 feet, minus 20 feet in elevation.
- Acceptable minimum allowable radius should also be specified.

HDD Design Concepts - Multiple Lines

– Multiple lines can be installed by placing single conduits in parallel holes, or by placing a bundle of lines in a single hole.

Lines in Separate Holes

Design Considerations

- Horizontal and vertical spacing and tolerances.
- Site-specific evaluation of directional accuracy
  - Length of crossing
  - Subsurface conditions
  - Potential survey system interference

Multiple Lines - Bundled

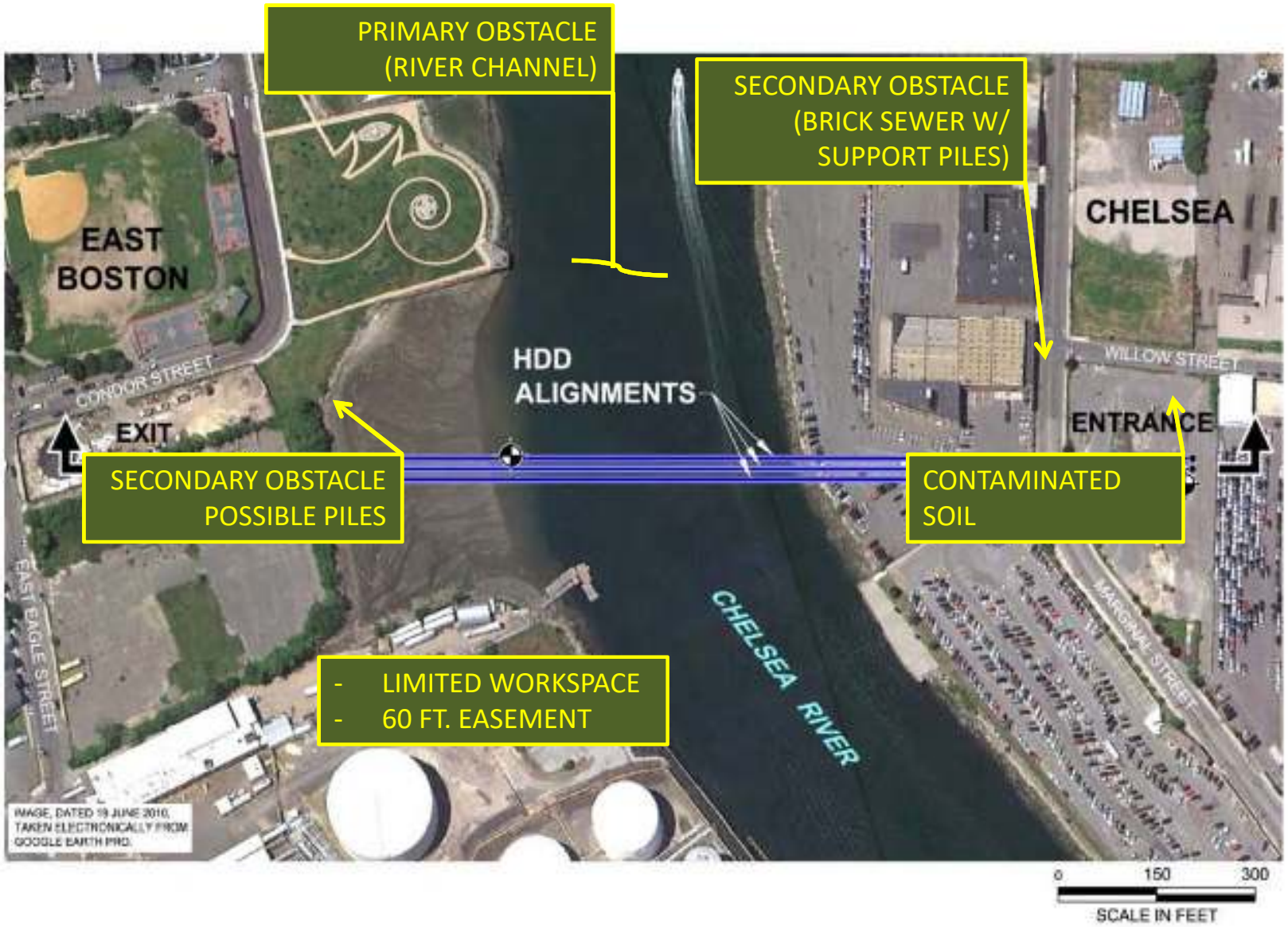
Design Considerations

- Multiple lines can be installed in the same hole by joining each to a common pulling head.
- Strapping the bundle is not necessary.
- Spacers may be required for steel pipe bundles.
- Bundle may roll during installation.

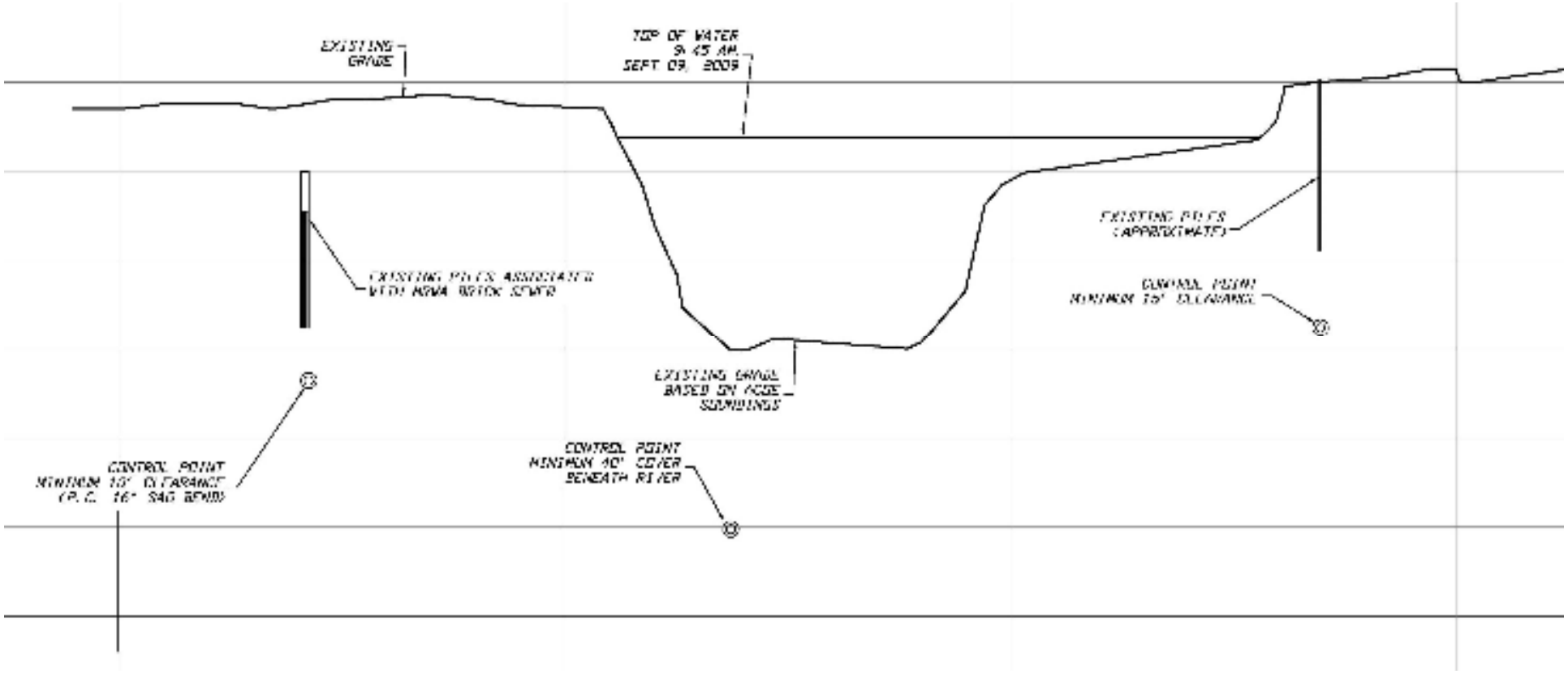
Design Considerations – Strapped Bundles

- Strapping the bundle can increase tensile capacity.
- Can make for easier pipe handling
- Risk of straps “hanging” on a rock ledge.

Obstacles Must be Defined

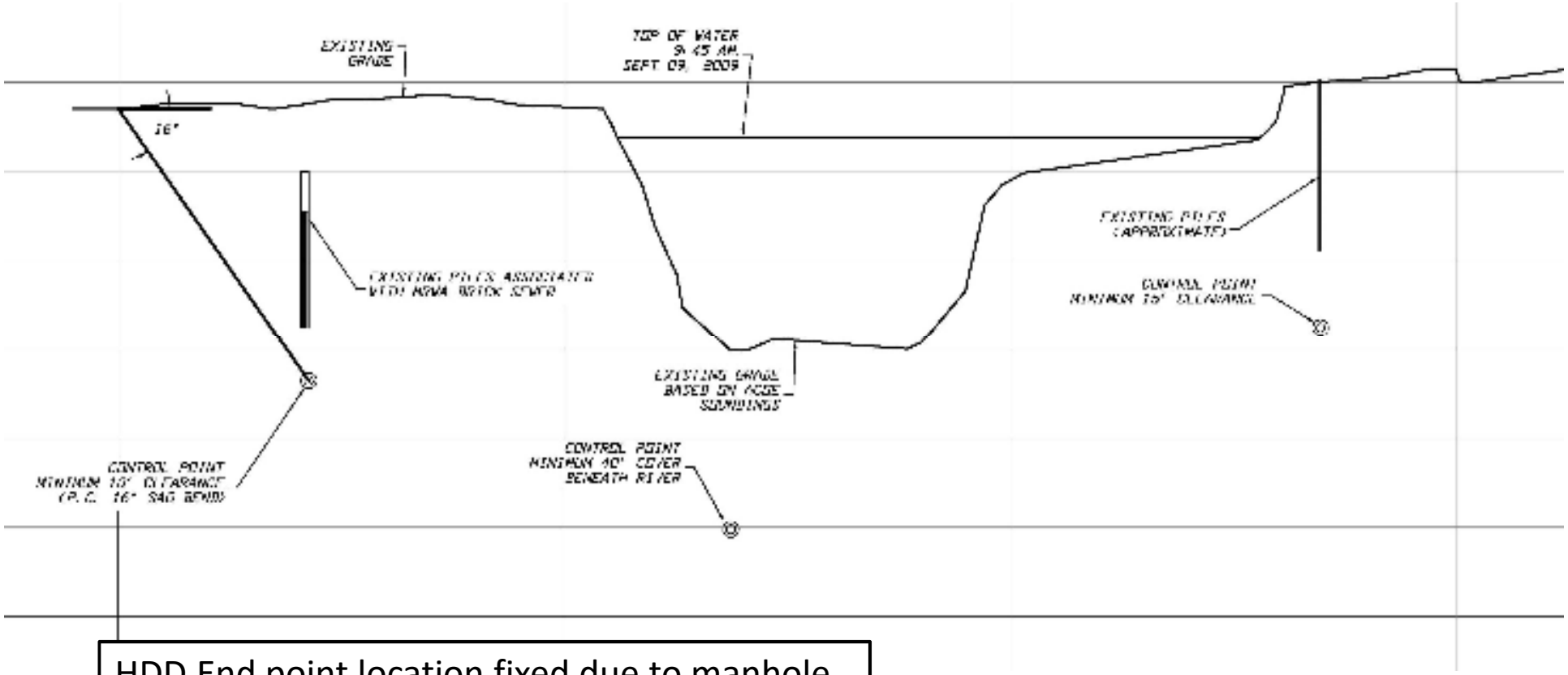


Profile Design Criteria & Geometry



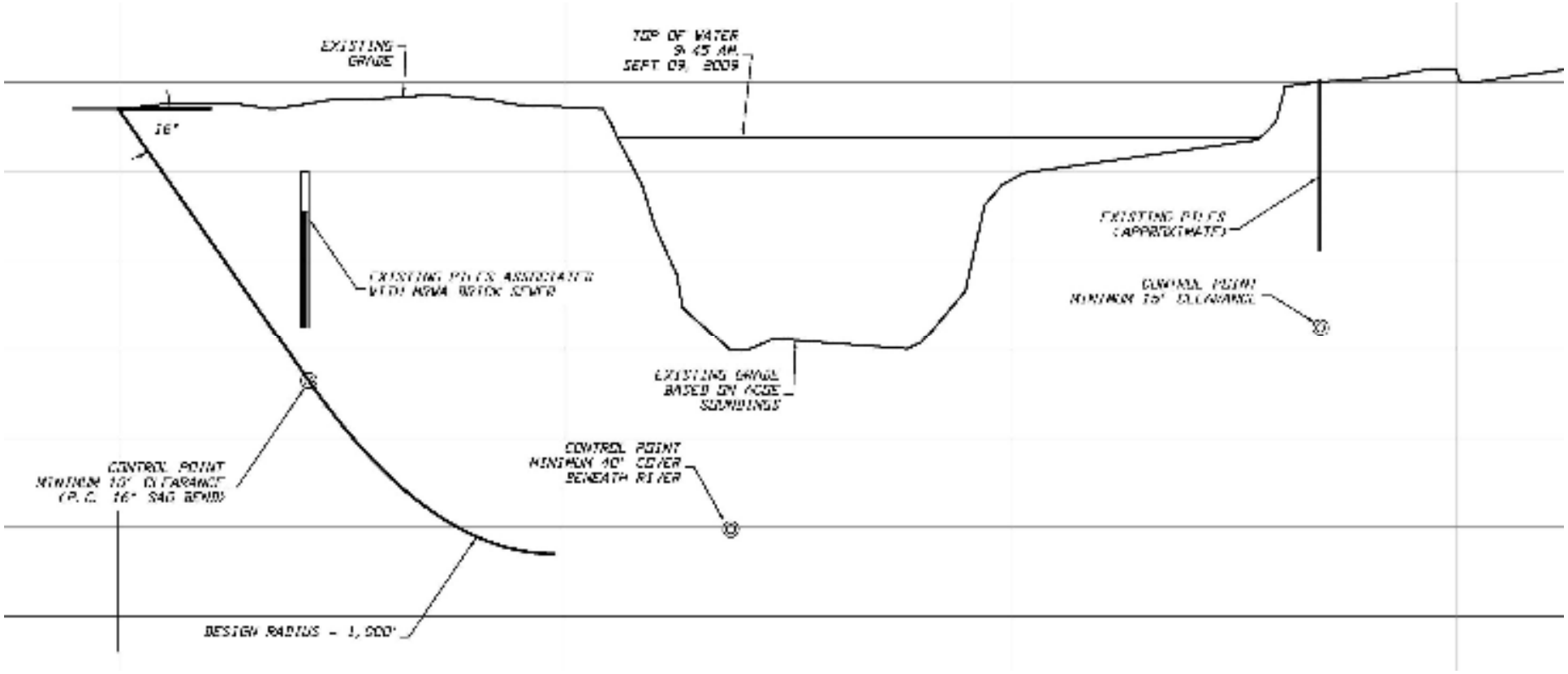
After obstacles are defined, design control points are established.

Profile Design Criteria & Geometry



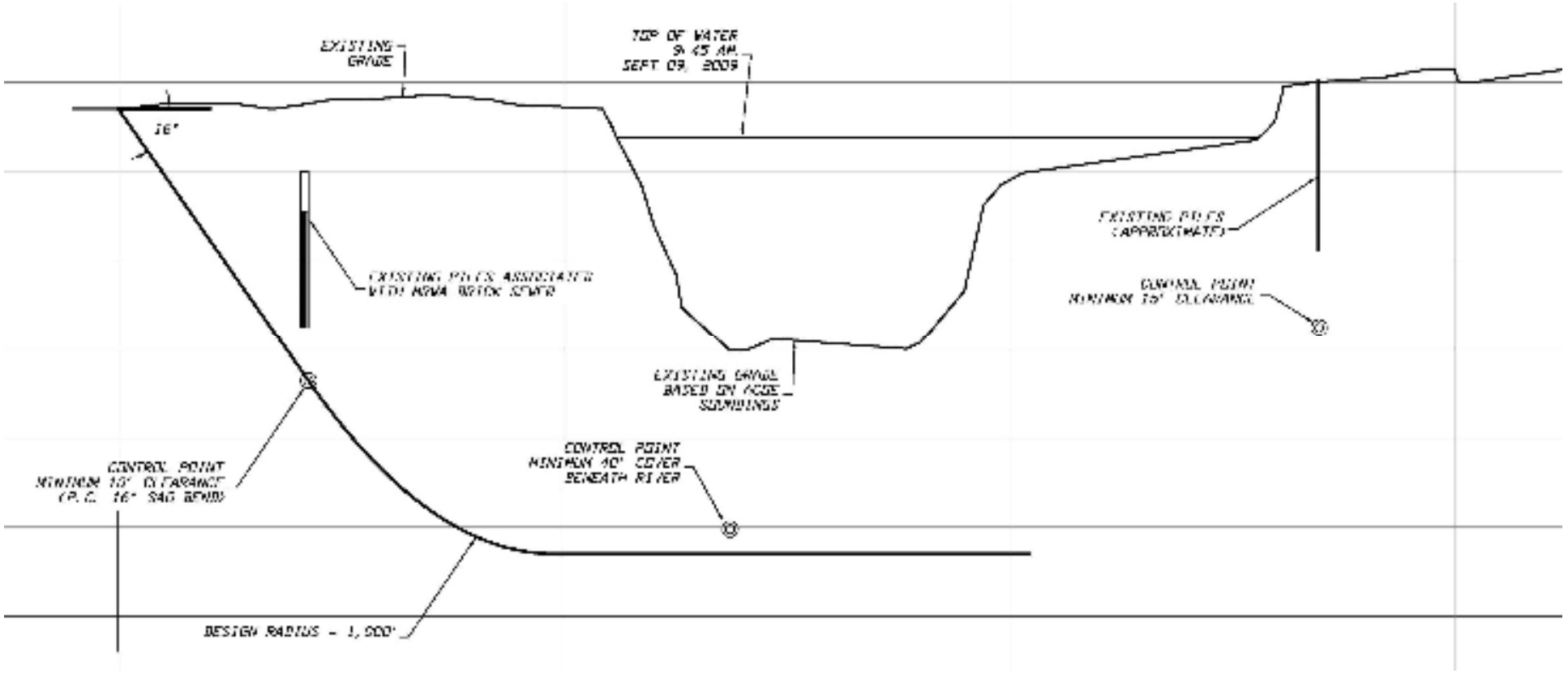
HDD End point location fixed due to manhole location and workspace limitations. 16 degree angle required. Workable as exit angle since lines to be installed were HDPE.

Profile Design Criteria & Geometry



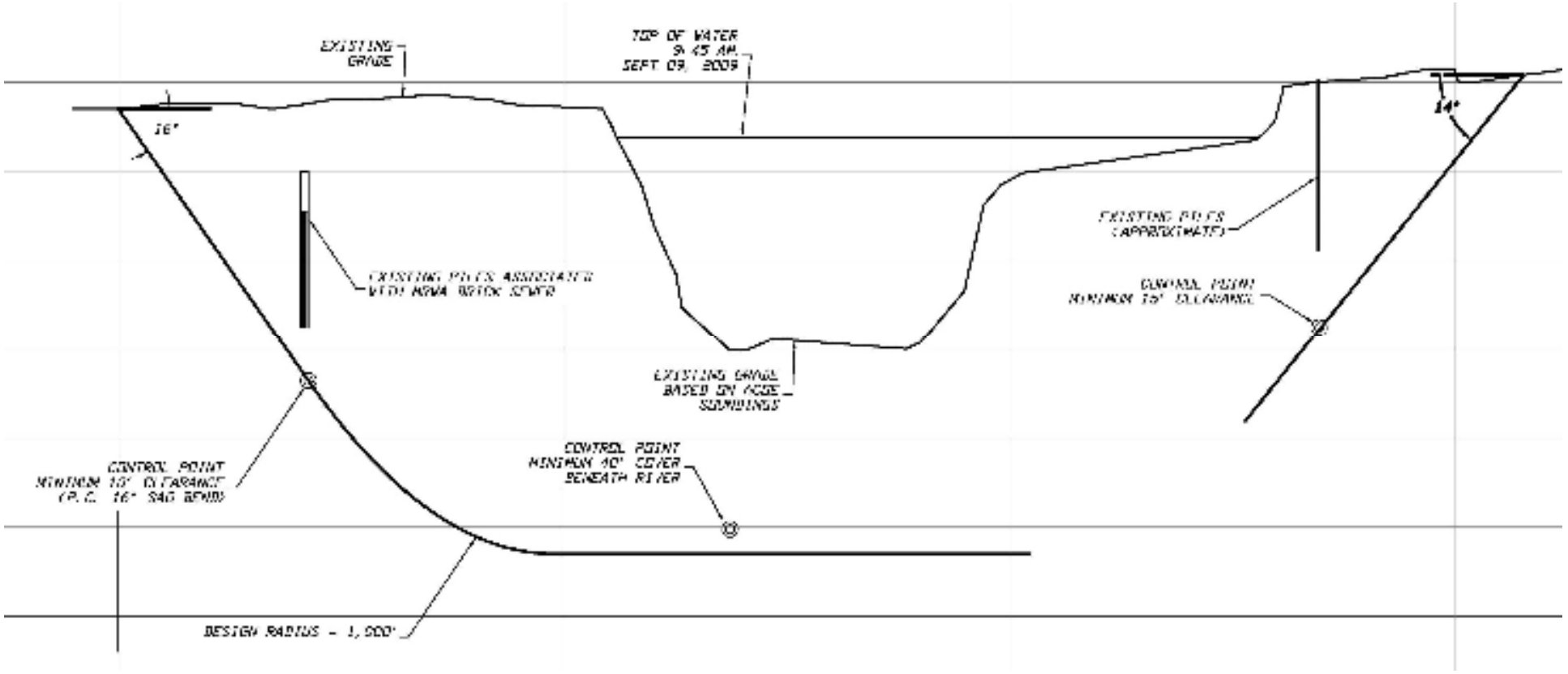
Design radius of 1,000 feet was used to keep the drilled segment above bedrock.

Profile Design Criteria & Geometry



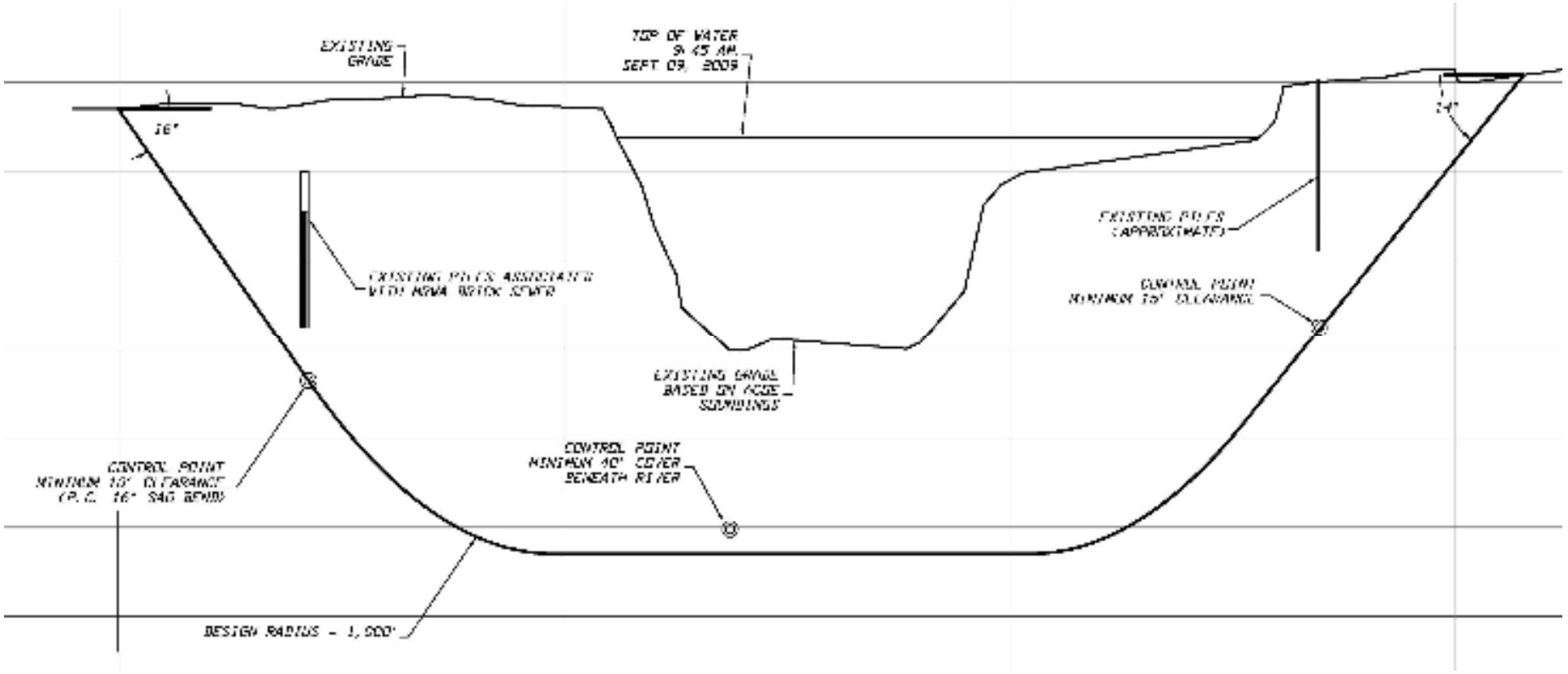
PI elevation controlled by radius. Exceeds 40’ cover criteria.

Profile Design Criteria & Geometry



Opposite end point also dictated by limited workspace which required 14 degree angle.

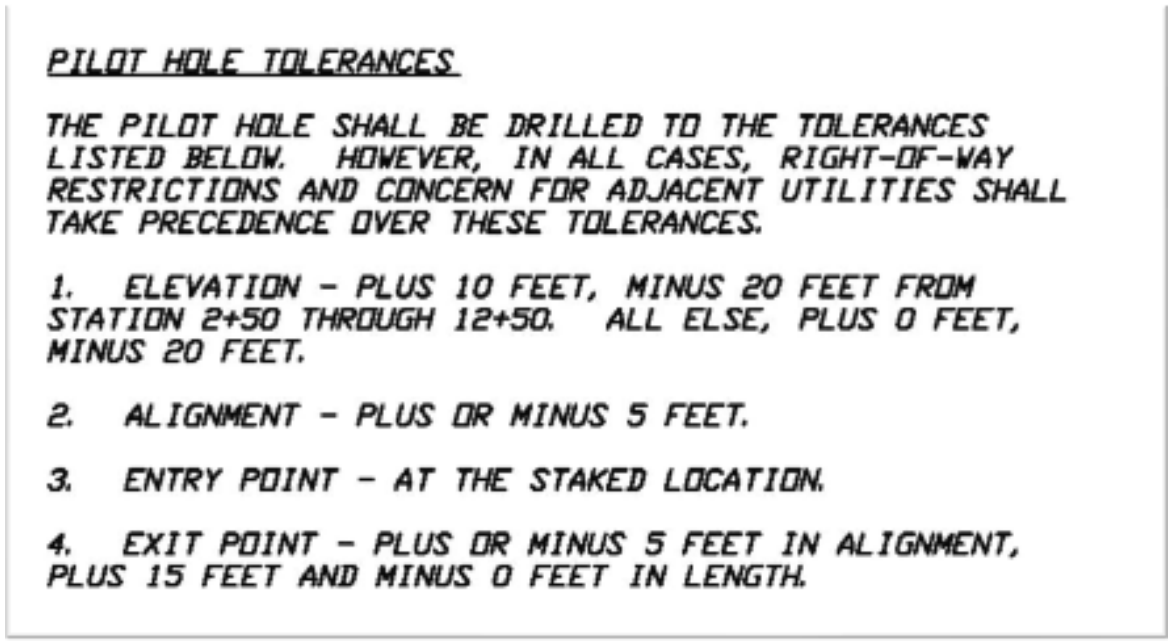
Profile Design Criteria & Geometry



Design profile is complete after joining the last two segments with a radius equal to 1,000 feet.

Pullsection Bundle Layout

Pilot Hole Tolerances



PILOT HOLE TOLERANCES

THE PILOT HOLE SHALL BE DRILLED TO THE TOLERANCES LISTED BELOW. HOWEVER, IN ALL CASES, RIGHT-OF-WAY RESTRICTIONS AND CONCERN FOR ADJACENT UTILITIES SHALL TAKE PRECEDENCE OVER THESE TOLERANCES.

1. ELEVATION - PLUS 10 FEET, MINUS 20 FEET FROM STATION 2+50 THROUGH 12+50. ALL ELSE, PLUS 0 FEET, MINUS 20 FEET.

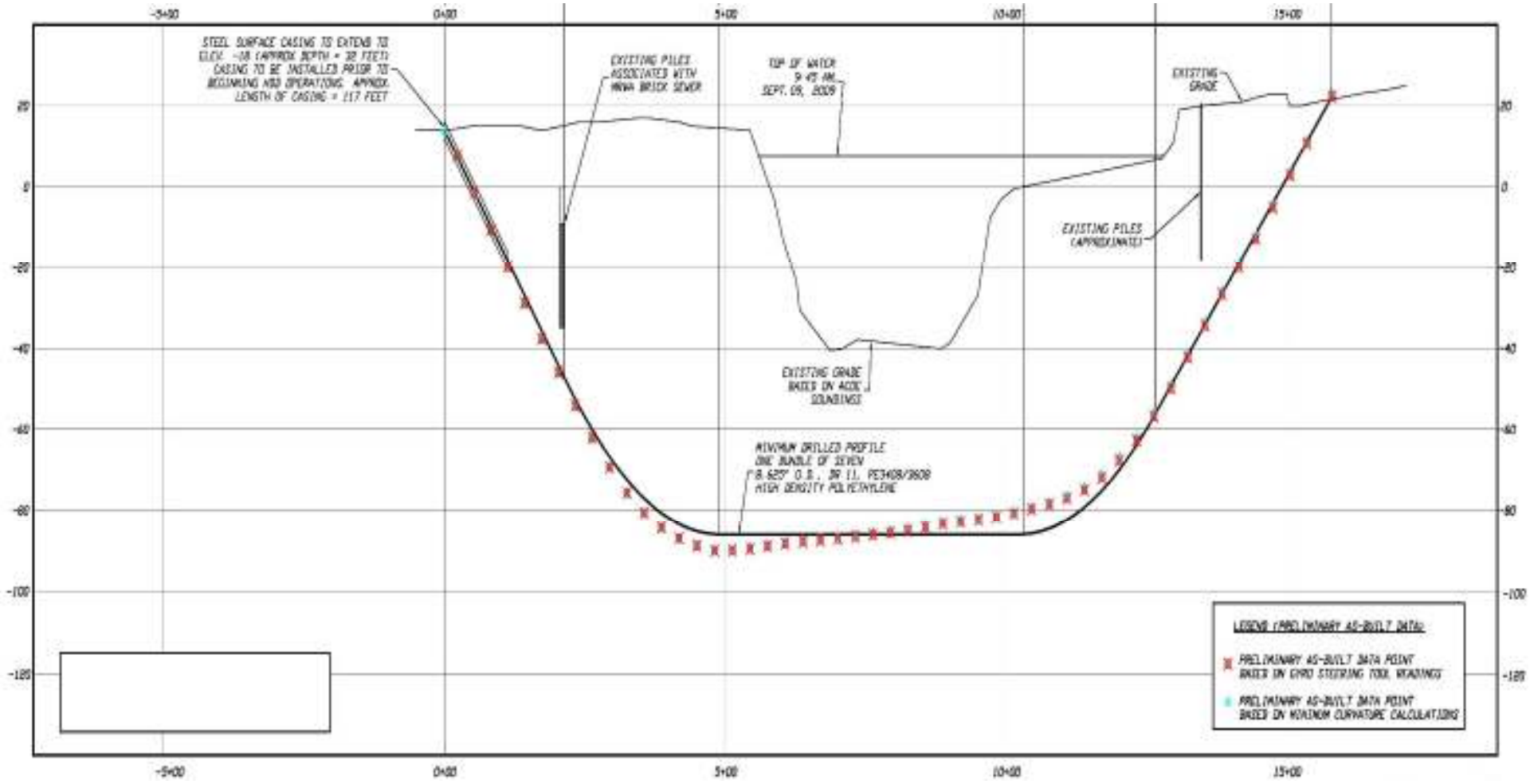
2. ALIGNMENT - PLUS OR MINUS 5 FEET.

3. ENTRY POINT - AT THE STAKED LOCATION.

4. EXIT POINT - PLUS OR MINUS 5 FEET IN ALIGNMENT, PLUS 15 FEET AND MINUS 0 FEET IN LENGTH.

- Elevation tolerances allowed 10 feet above centerline over the majority of the crossing.
- Alignment tolerances provided 10 feet of separation at centerline (minimum).
- Minimum radius not specified in the pilot hole tolerances since HDPE conduits were being installed.

As-built Pilot Hole



Sources of ***Frictional*** Drag on Pipe*

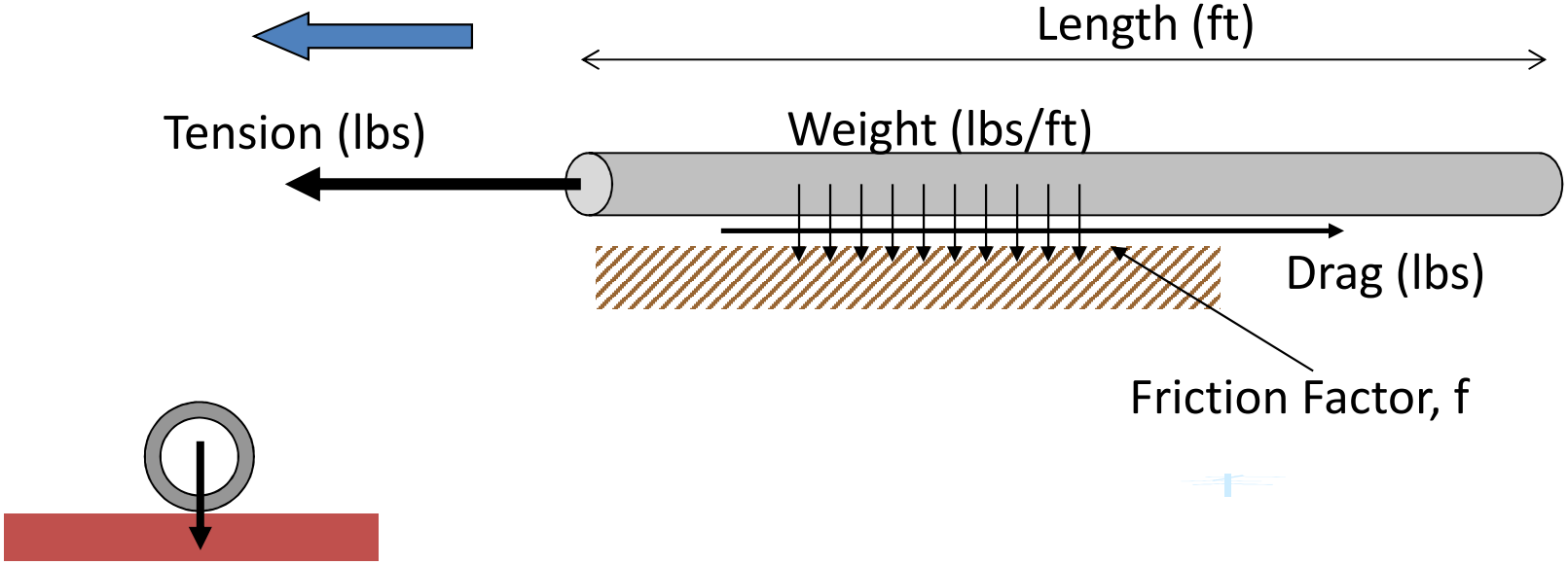
1) Direct weight↓ or buoyancy↑ effects

2) Pipe stiffness at bends

3) Pipe pulling force/tension at bends ("Capstan" effect)

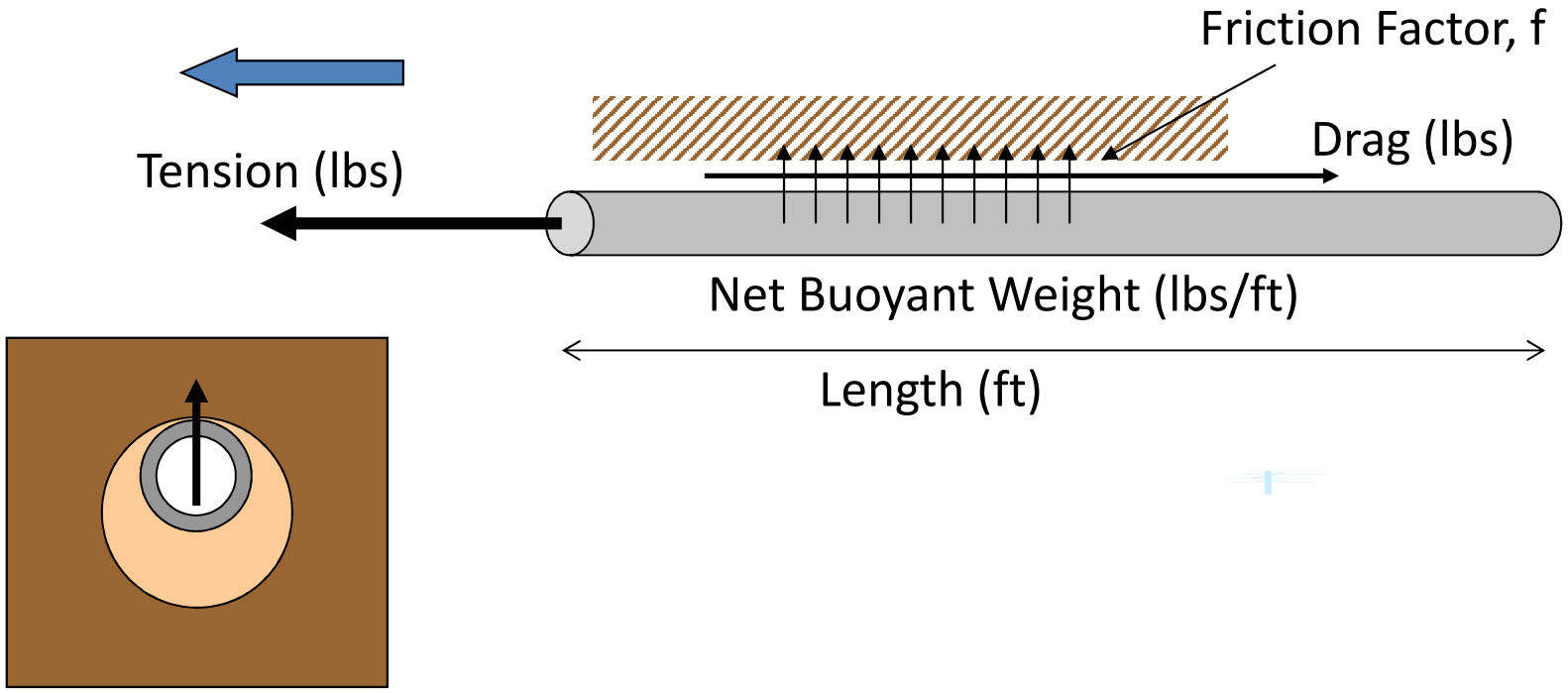
* Conventional "Coulomb" type friction is typically assumed (i.e., drag proportional to local surface pressure)

Frictional Drag Due to Weight of Pipe



Tension (lbs) = Dead Weight (lbs/ft) x Length x Friction Factor

Frictional Drag Due to Buoyancy of Pipe

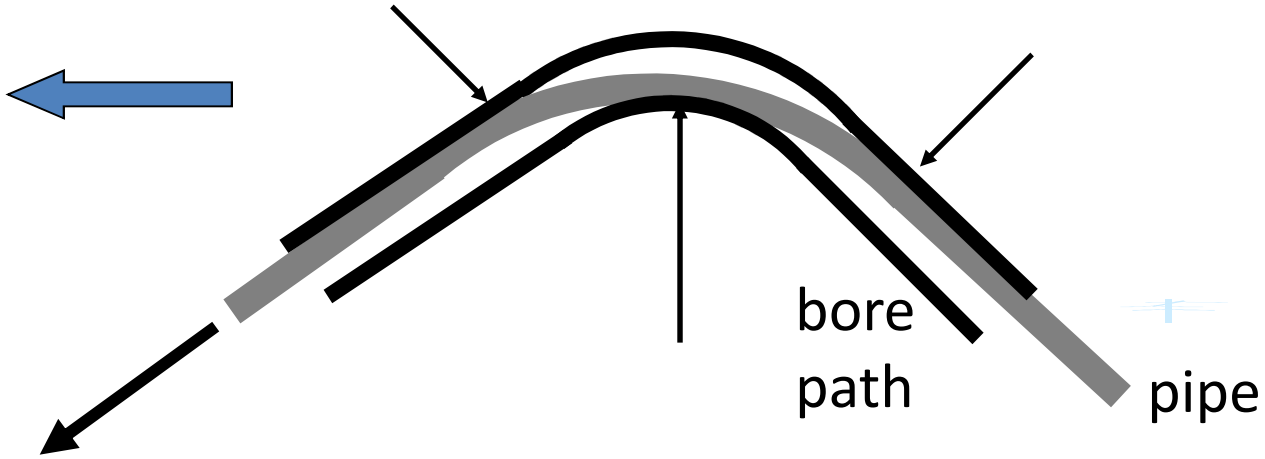


Tension (lbs) = Buoyant Weight (lbs/ft)* x Length x Friction Factor

* Note: In some cases (e.g., HDPE) buoyant weight possibly >> dead weight; thus may use ballast to reduce buoyant weight.

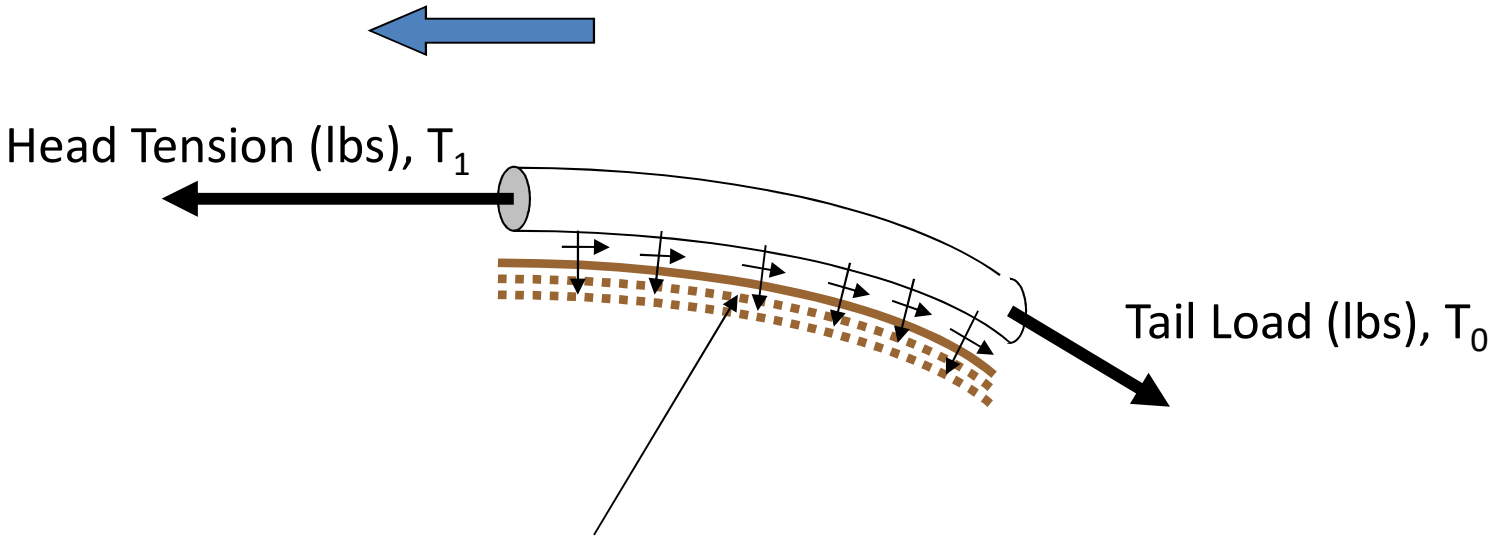
Increased Frictional Drag Due to Pipe Stiffness

Concentrated Local Reaction Forces



Reaction (Bending) Forces ⇨ Added Frictional Drag

Additional Frictional Drag Due to Tension at Bends ("Capstan" Effect)



Increased Surface Pressure ⇨ Added Frictional Drag

$T_1 > T_0$

Fluidic Drag on Pipe

Different treatments exist; for example:

- ASTM F1962 (relatively small effect)
- PRCI – or AGA Method (relatively large effect)
- Other (e.g., Duyvestyn: *Comparison of Predicted and Observed HDD Installation Loads for Various Calculation Methods*)

HDPE Pipe

NOTE: PPI BoreAid™ is a free, web-based program that may be used to perform the installation and post-installation calculations in ASTM F1962. The program is available to the public at www.plasticpipe.org.

Operational Loads

- Similar to those involved with burial by traditional open cut with one exception – HDD segments have elastic bends.
- Stresses imposed by elastic bends should be checked in combination with other longitudinal and hoop stresses resulting from operation.
  - Internal pressure
  - External pressure
  - Thermal expansion
  - Bending

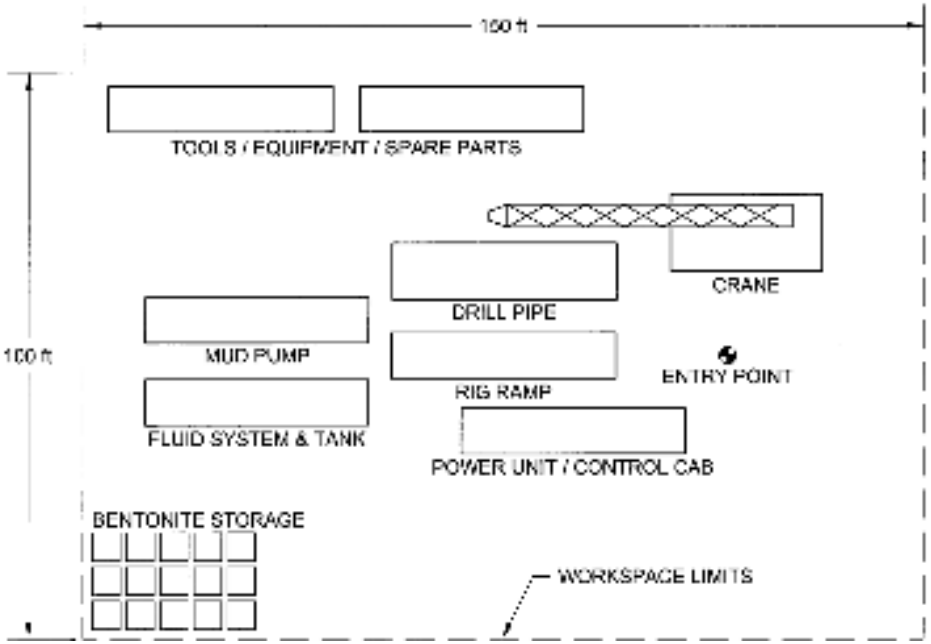
Design Considerations – Workspace

- Requires fairly linear workspace for pull section layout and fabrication.
- May require multiple pull section segments with tie-in welds during pullback (increases the risk of getting stuck).

Design Considerations – Coatings

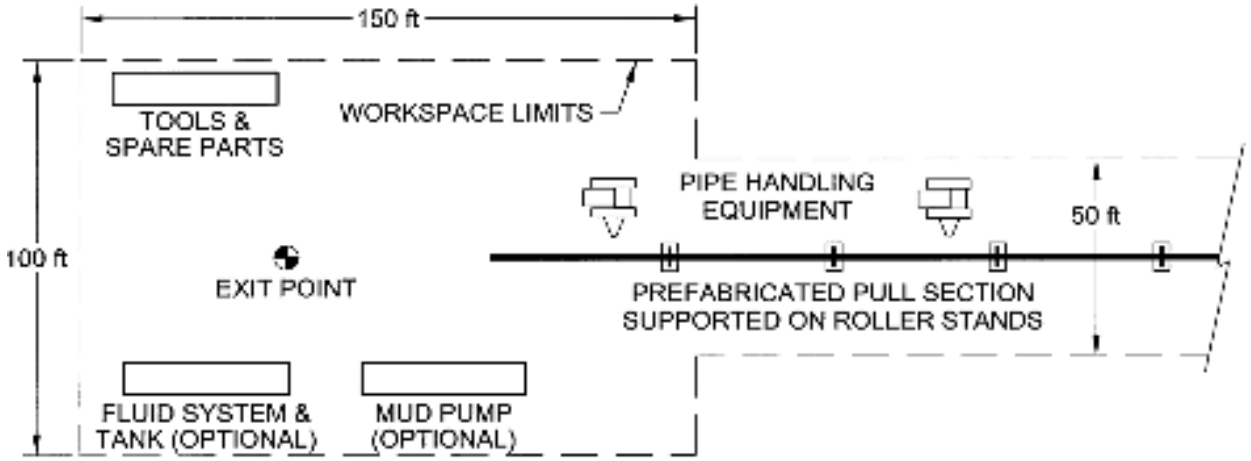
- Steel requires corrosion coating.
- Armor coatings should be used when the HDD installation takes place through abrasive material.
- Compatible Field Joint Coatings Risk of coating damage during installation.

Work Space



HDD Entry Side

HDD Exit Side



Drilling Fluid Considerations

All phases of HDD involve pumping drilling fluid through the drill string to a bit or reamer downhole

- Ideally the fluid flows back to the entry or exit point through the drilled annulus
- In reality drilling fluid flows in the path of least resistance

This can result in:

  - Lost circulation - dispersal of fluid to the surrounding soil
  - Inadvertent returns - surface discharge of fluid at a random location

Drilling Fluid Functions

- Hydraulic excavation
- Transmission of hydraulic power
- Transportation of drilled spoil
- Cooling and cleaning of cutters
- Reduction of friction
- Hole stabilization
- Soil modification

SOIL TYPES

- COARSE SOILS

  (Porosity & Permeability)

  - SAND
  - GRAVEL
  - ROCK

- FINE SOILS

  (Water Sensitive formations)

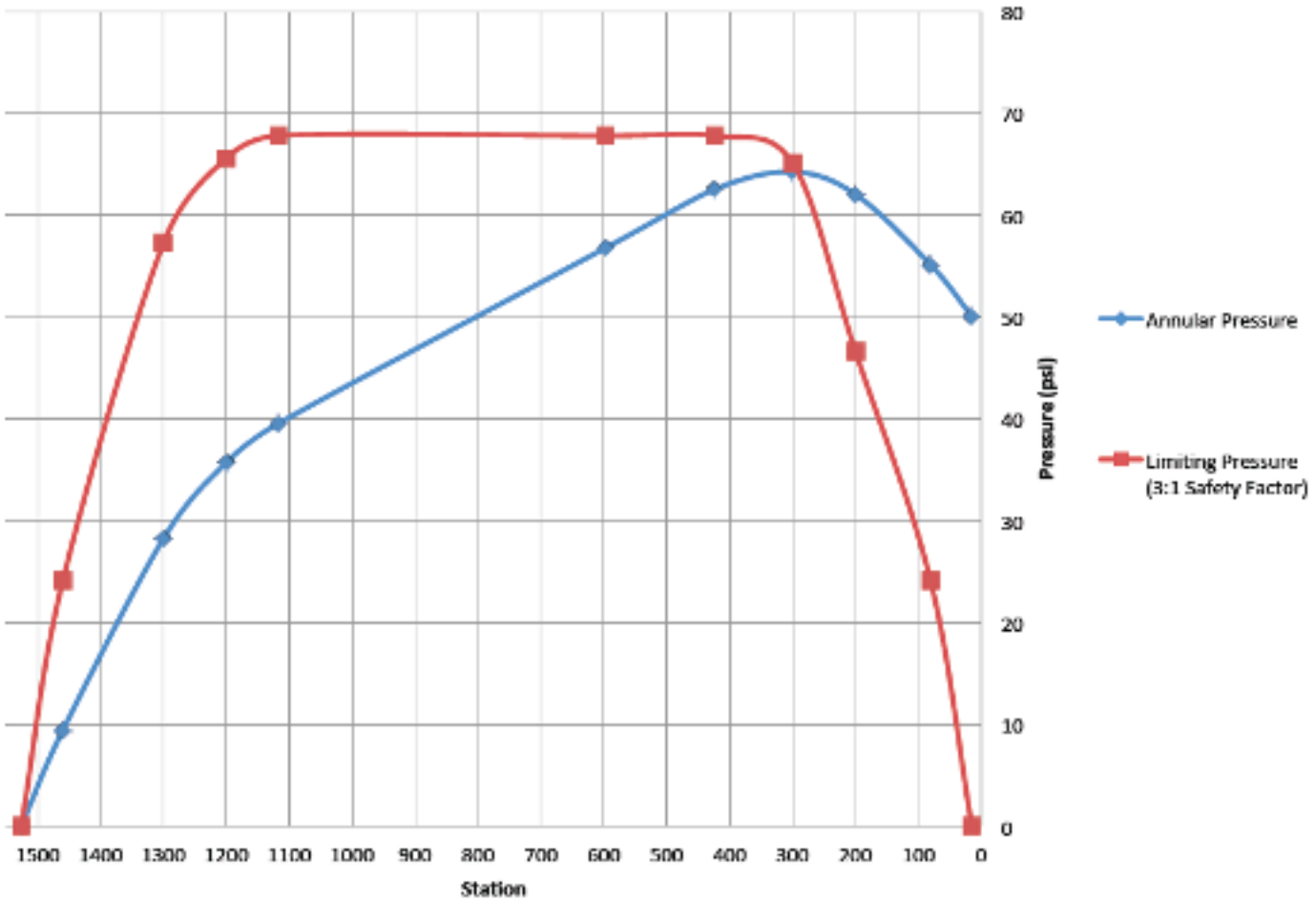
  - CLAY
  - SHALE

Inadvertent Returns

- Also known as *FRAC OUT!!*
- Often seen in permeable soils (gravel) or jointed materials (clay, weathered rock)
- Very difficult to predict where
- Very difficult to predict the volume

Inadvertent Release of Drilling Fluids

Hydrofracture Analysis



Mitigation of Inadvertent Returns

- Have methods of rapid detection
- Inventory containment materials
- Establish ingress/egress routes
- Establish agreed clean-up methods prior to construction

Post-Construction Disposal

Drill Fluid Disposal

- Land farming – spread over an open area and mixed with native soil
- Mix with backfill materials
- Transport to landfills
- Proper documentation includes:
  - Volume removed
  - Contaminate testing
  - Property Owner agreement, landfill license

HDD Risks

- Drilling Fluids – surface inadvertent returns and subsurface contamination
- Product pipe damage
- Accuracy of installation
- Geotechnical conditions (cobbles/boulders, gravelly conditions, weathered rocks, etc.)
- Underground utilities
  - Cross bores

Issues Related to Gas Pipe Installations

- Weak link segments between the pull head and the pipe are important and required. These are commonly smaller or thinner walled pipe, or something else that is designed by an engineer.
- Pre reaming can be important to also minimize pull tensions.
- Testing should always be done after the HDD installation in case it was damaged during installation.
- Also in case the pull head tears off between the new pipe and pull head there should be a solid plug to keep mud out.

Issues Related to Gas Pipe Installations

- All gas companies are required to have O&M manuals which typically include construction standards, they are unique to each company usually and in some cases will vary by division.
- *Most likely Columbia has one for each state*
- Each state may also have additional standards. ASTM, API, ASME and other standards are also used.

Issues Related to Gas Pipe Installations

- Gas construction is different than water construction with the major difference being compliance with CFR 49 Part 192 which governs gas distribution and transmission.
- All personnel must be qualified for each Covered Task performed by that individual. Covered Tasks include but are not limited to:
  - plastic fusion,
  - steel welding,
  - operation of valves,
  - line stopping, tapping,
  - cathodic protection,
  - removing, renewing customers, etc.

Issues Related to Gas Pipe Installations

- There are minimum cover requirements for both gas mains and services.
- Weak links must be used for HDD.
- All plastic materials must conform with ASTM D2513.
- Tracer wire is required for all gas lines. Tracer wire installation can be a big challenge. Need to use stainless steel cable and may need redundant wires.

Issues Related to Gas Pipe Installations

- All buried metallic fittings require cathodic protection.
- Squeeze off machines have to be grounded.
- A Maximum Allowable Operating Pressure must be established for all gas lines and MDPE is limited to 60 PSI and must be tested to 1.5 times the operating pressure (60 psi system, 90 PSI test).
- Meters are usually located adjacent to structure versus at property line (there are some exceptions).

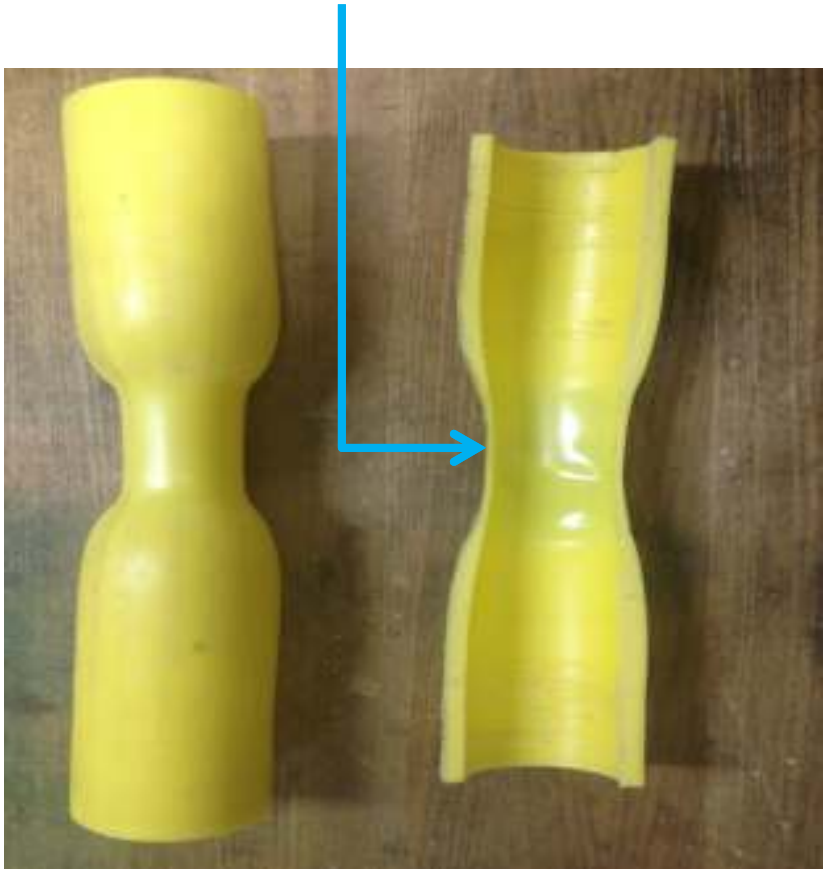
Issues Related to Gas Pipe Installations

- Some states require curb stops on service lines.
- Excess flow valves are required for most residential customers.
- Records must be kept for all pipelines in operation.
- Gas leaks are graded with associated repair timelines. Hazardous leak must be repaired right away.
- Each state has the option for requiring additional requirements beyond the Federal rules (like OSHA).

Heaved Road During Back-reaming

Stretched HDPE Pipe

Wall thickness reduced



Pipe diameter reduced

Typical Pull Force Ratings for HDPE

2" - 2,000 lbs

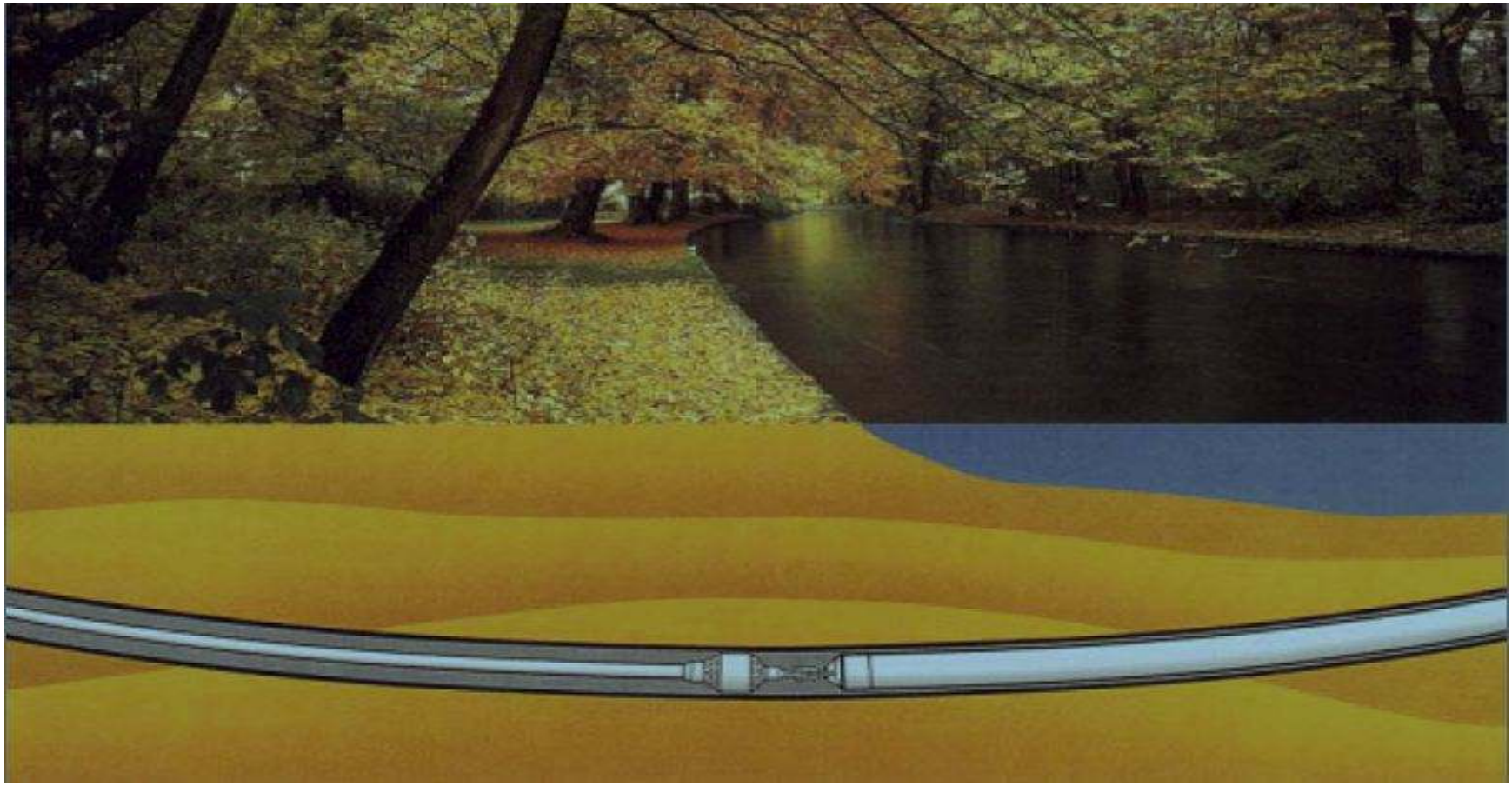
4" - 6,800 lbs

6" - 14,400 lbs

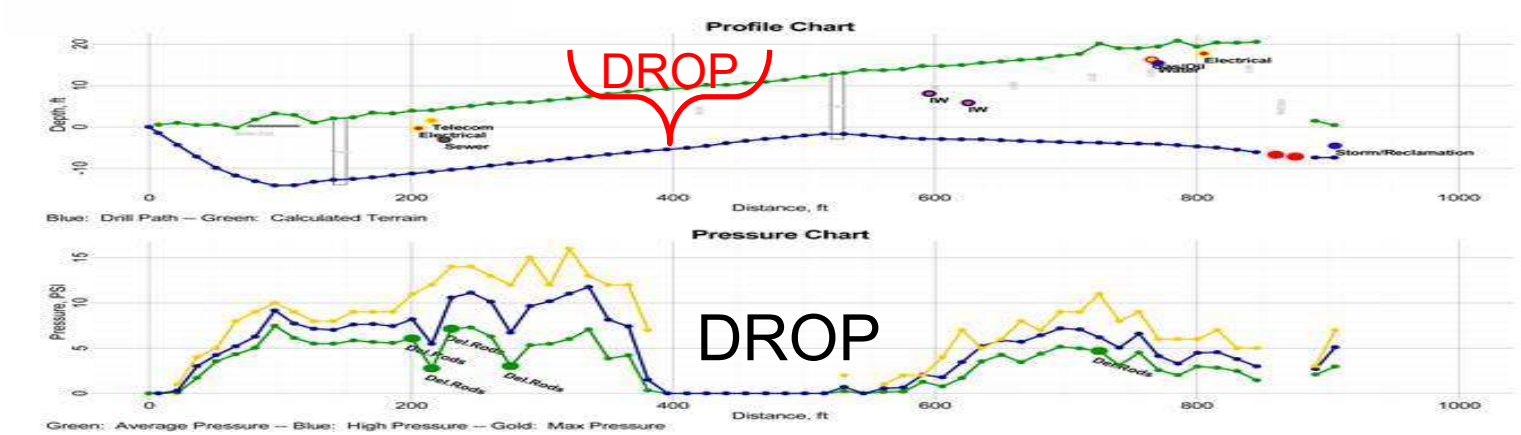
8" - 34,000 lbs

Pull force ratings are dependent on wall thickness and exact material make up. Pipe manufacturers can provide actual ratings.

Environmental Protection



Cross Bore Pressure Drop



HDD Challenges

- Increasingly congested areas to work in

Avoiding Cross Bores

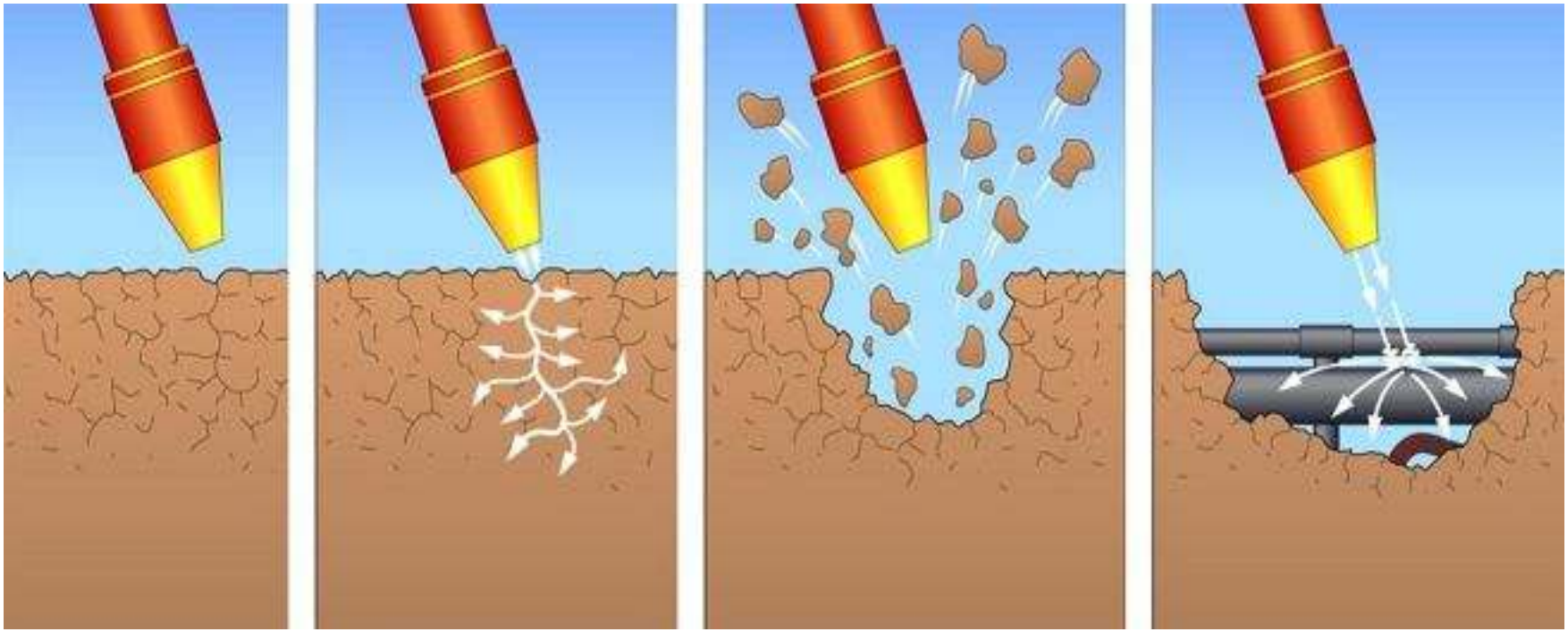
- Daylighting utilities
  - Allows for less intrusive locating of existing utilities

Avoiding Cross Bores

- Vacuum Excavation

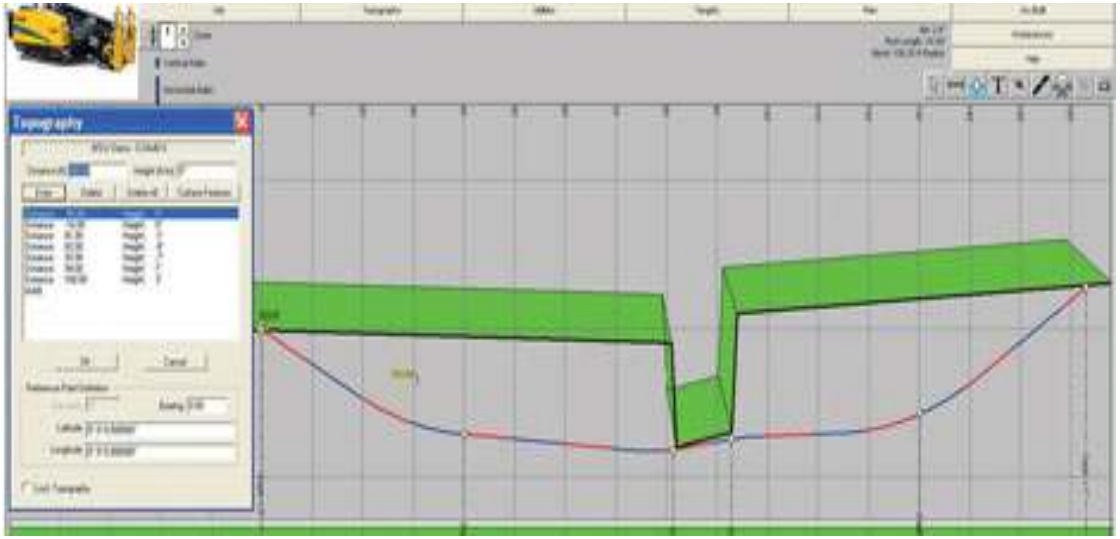
Cross Bore Prevention

- Water or air can be used to break up surrounding soils and vacuum is used to remove soil



HDD in the Future…

- Bore Planning and As-Built Technology
- GPS Based Planning and Locating Systems



HDD in the Future…

- Better Drilling Fluid Management and Recycling Systems – Centrifuge Systems

HDD in the Future…

- Remote Operating and Rig Monitoring Systems
- Operator Classifications and Certification

The Future!

- Digital Job Site:
  - GPS based job plans
  - Google Map overlays
  - GPS locating
  - Real time bore profile at the drill rig

Conclusions

- Technologies are developing!
  - Exciting and growing market!
  - More hybrid methods!
- Correct method must be selected for project, surface and subsurface conditions!
- Capital cost is only one factor, also consider:
  - Life cycle costs
  - Social costs
  - Environmental impacts
  - Constructability

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Thank you!!

Discussions!

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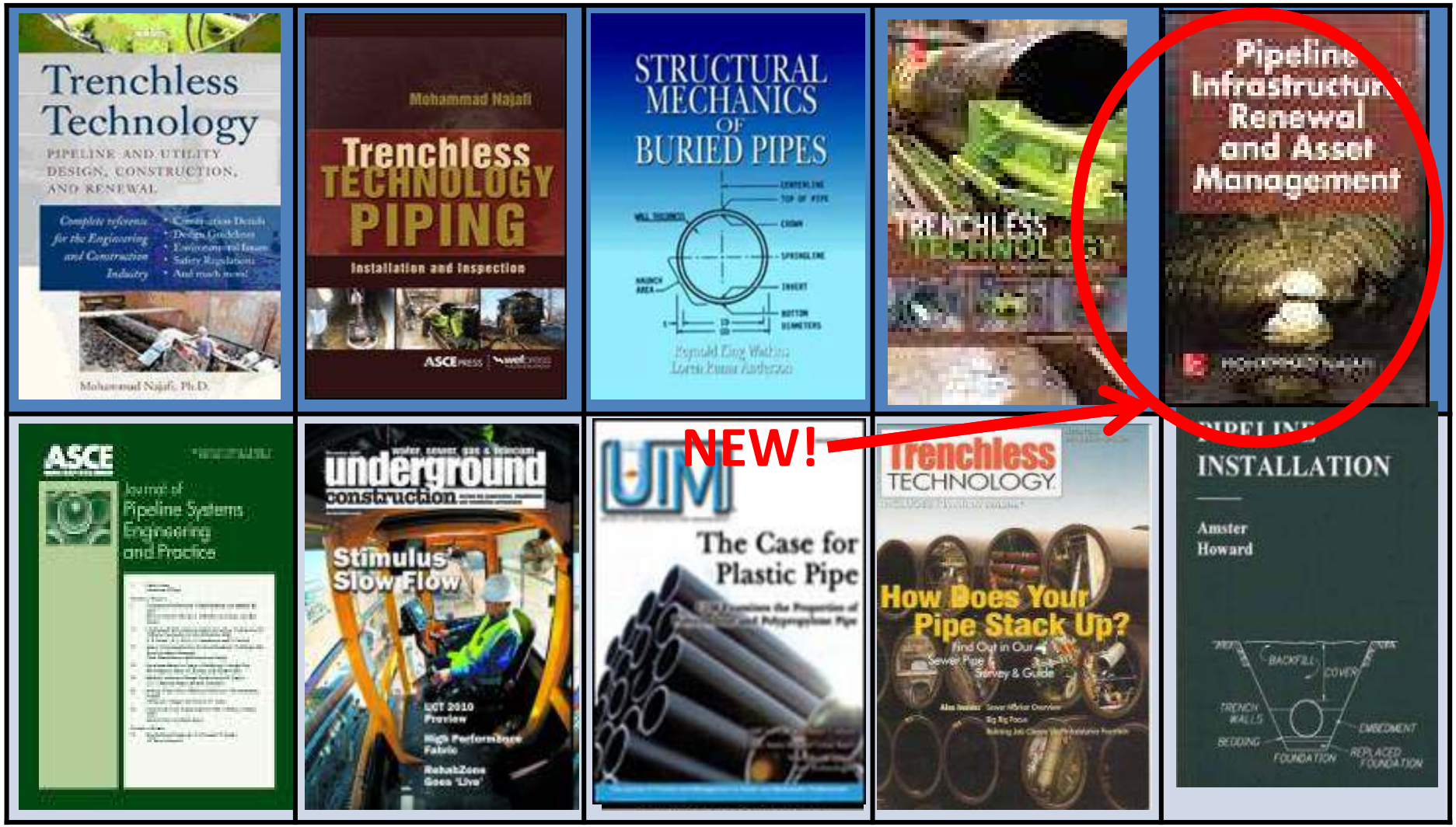
Some Resources…



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