Long Pulls by Horizontal Directional Drilling

Brief History of HDD as a Pipeline Installation Methodology

- HDD developed in the 70's
- Power cable then road crossings for gas
- Martin Cherrington with Titan Contractors for PG&E
- Pajaro River crossing in Northern CA with 5" mud motor

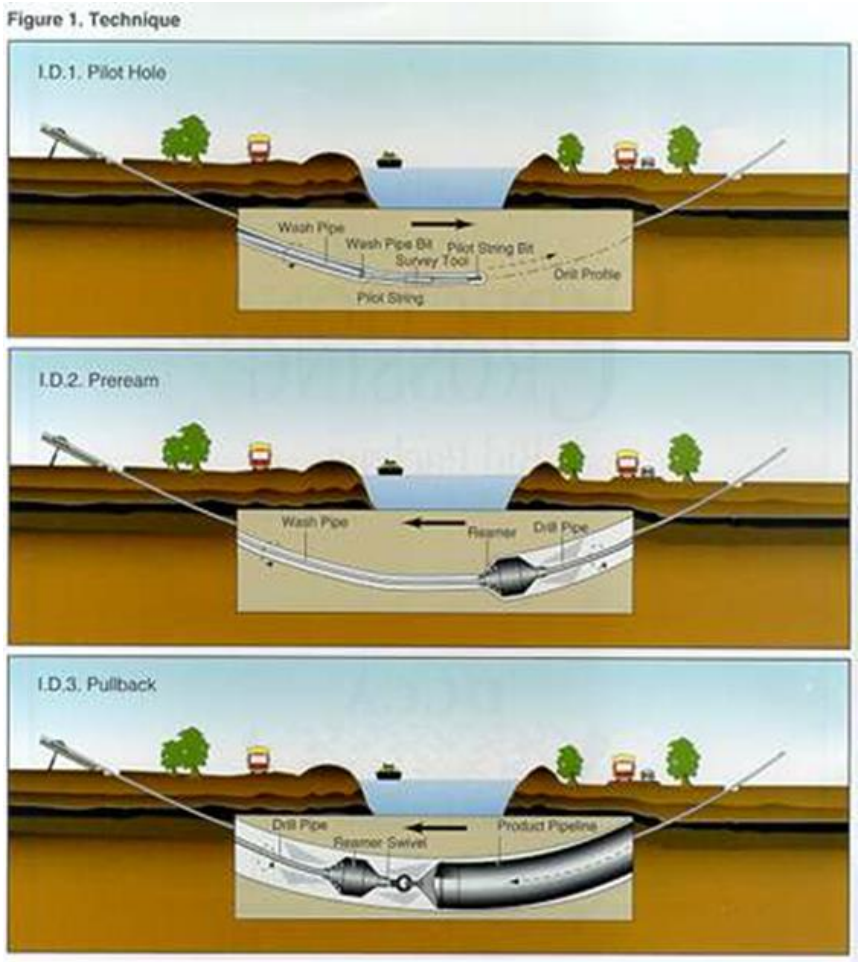
  - ~500 LF pilot taking 1 month
  - Tracked using a single shot survey system
  - Discarded drilling tools that drill back to surface.

Brief History of HDD as a Pipeline Installation Methodology

- Current industry practice took off in the 80's and 90's
- Drill rig capabilities & steering technologies (limited growth)
- Initial growth in smaller diameter pipe
- Tremendous growth in the waterworks market in the last 20 years in the US and abroad
- Rivers the size of the Mississippi are crossed by HDD with minimum impact to the environment
- The longest steel HDD with steel pipe in the US…
- The longest thermoplastic HDD in US to date is…

Basics of Horizontal Directional Drilling

- Guided pilot hole is drilled along a bore path
- Drilling fluids are injected into the hole to stabilize and lubricate
- Back reamer is used to enlarge the pilot hole
  - Multiple passes are required to accommodate pipe OD
  - Borehole 1.5 x OD of new pipe or pipe OD + 12”
- Product pipe is pulled through the bore hole



Where is Horizontal Directional Drilling utilized?

- Water, Wastewater, Conduit, Casing, Gas, Comm., etc.
  - Waterbody crossings, outfalls and shore approaches
  - Interstate, Highway, county road, driveway and parking lot crossings
  - Conflicting utilities such as gas lines or storm drains.
  - Pipeline relocation/replacement

Bay County, FL – Hathaway Bridge

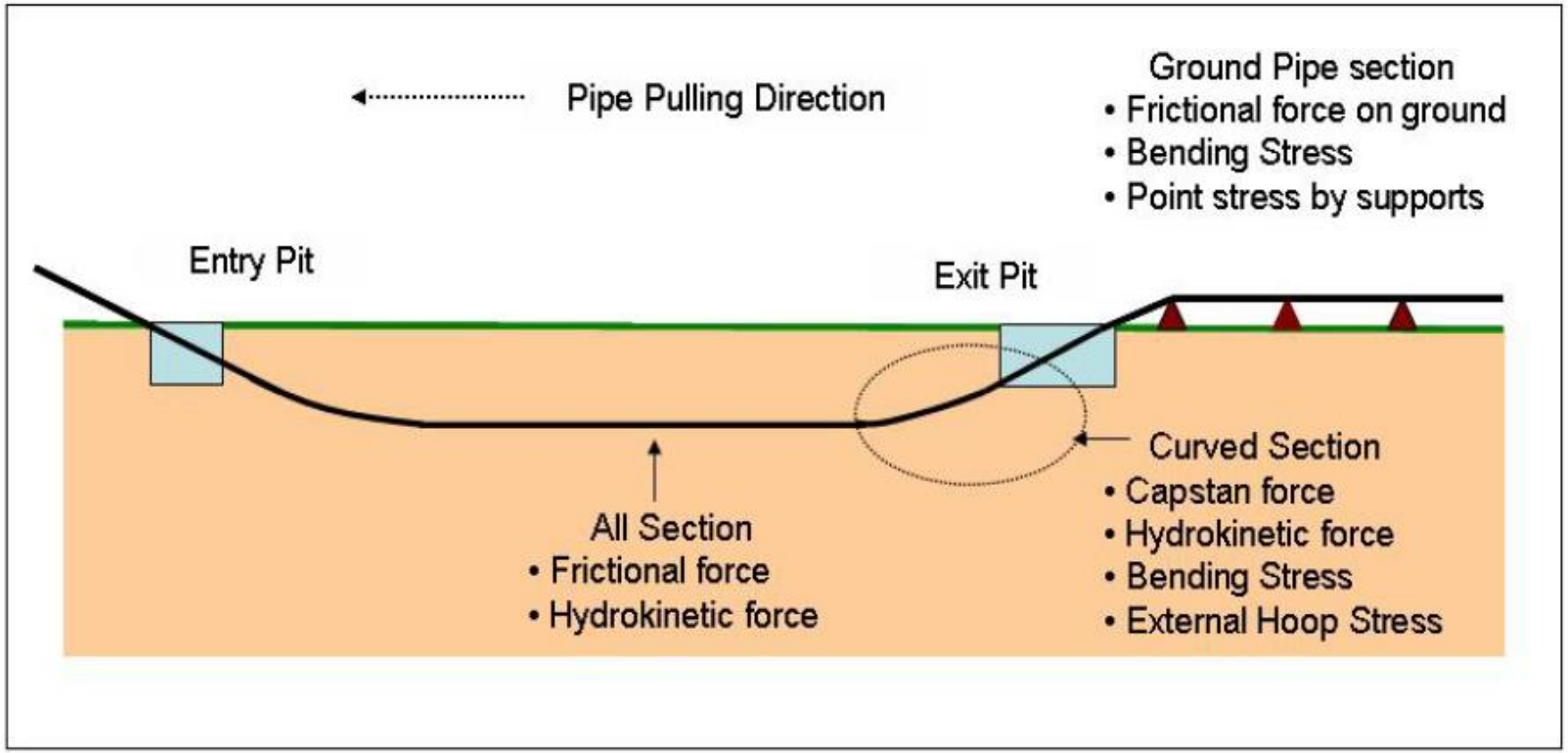
- Constructed in 2003, replacing St. Andrew Bay Bridge
- Accommodates a high volume of daily traffic
- 4500 LF 24” ductile iron water main also installed on bridge
  - Supported with concrete
  - Not easily accessible
- Leaks detected in 2017
- FDOT requested long term solution with pipe off the bridge
- DI Bypass

Design-Build Team

- Selected by Bay County
- Contractor: Marshall Brothers Construction Inc.
- HDD Subcontractor: Mears Group
- Engineer: Dewberry Engineers Inc.
- Partnered with HDD risk mitigation specialist Brierley & Associates
- Bay County Engineer Representation: Mott McDonald

HDD Material Properties to Consider

- Tensile loading of joint
- Bending capability
- Critical buckling capability and deflection



HDD Pull Force Standard Assumptions

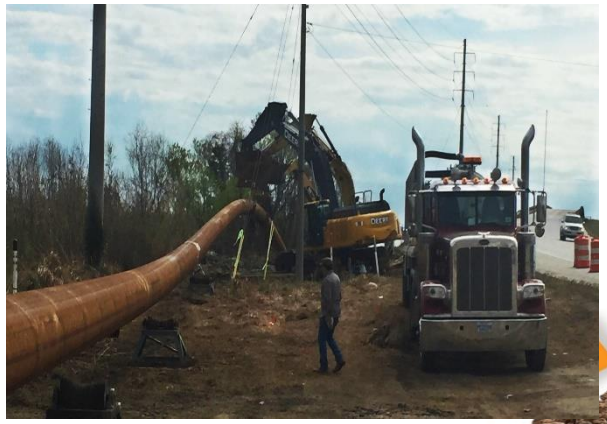
- Standard assumptions:

	FPVC	Steel	HDPE
• Tensile stress at yield	7,000 psi	35,000 psi	3500 psi
• Modulus of elasticity	400k psi	29M psi	110K (ST) 28K (LT)

  - COF drill mud = 0.3
  - COF rollers = 0.2
  - COF ground = 0.5
  - Mud density 12.5#/gal (1.5 sp.gr.)
- Follows ASTM F1962 methodology

HDD Pipe Materials

- Steel
- HDPE
- PVC
  - Fusible C900 PVC®
  - Mechanically restrained joint
- Ductile Iron



Design – Material Selection

- Steel & Ductile Iron
  - Ruled out due to corrosion, constructability and cost
- HDPE
  - Concerns with disinfectant oxidation
  - Insufficient history with HDD installations >5000 LF
- Fusible PVC
  - 15 HDDs over 5,000 LF
  - Bay County >95,000 LF of Fusible PVC pipe installations over 15 years
  - Dewberry familiar with material, and have used it for previous HDD projects including a 36” FPVC and two (2) - 30” FPVC HDDs replacing failed HDPE pipe

Horizontal Directional Drilling Considerations

- **Corrosive Soils**
- **ID/OD Relationship**
- **Pipe fusion and laydown area**
- **Insertion trench**
- **Drill Mud**
- **Geotechnical information**
- **Bend radius**
- **Pull Force required**
  - **Rollers**
  - **Buoyancy modifications**
- **Depth-** critical buckling pressure
- **Pressure test**
- **Connections**

HDD Rig Sizes and Capabilities

Maxi Class

- Over 100,000# pullback
- Over 12,000 ft-lbs torque
- Over 10,000 feet drive lengths
- Depths up to 200 feet deep
- Up to 48” diameter installations
- ≤ 30 ton machine weight
- Typical rack angle 8-18 degrees

(common not to exceed 12 deg.)

Hathaway HDD Rig Size

- 660K HDD Rig
- 140K HDD Rig
  - 1 week intersecting pilot

Typical Drill Rig “Spread” or Set Up – Maxi-Rig

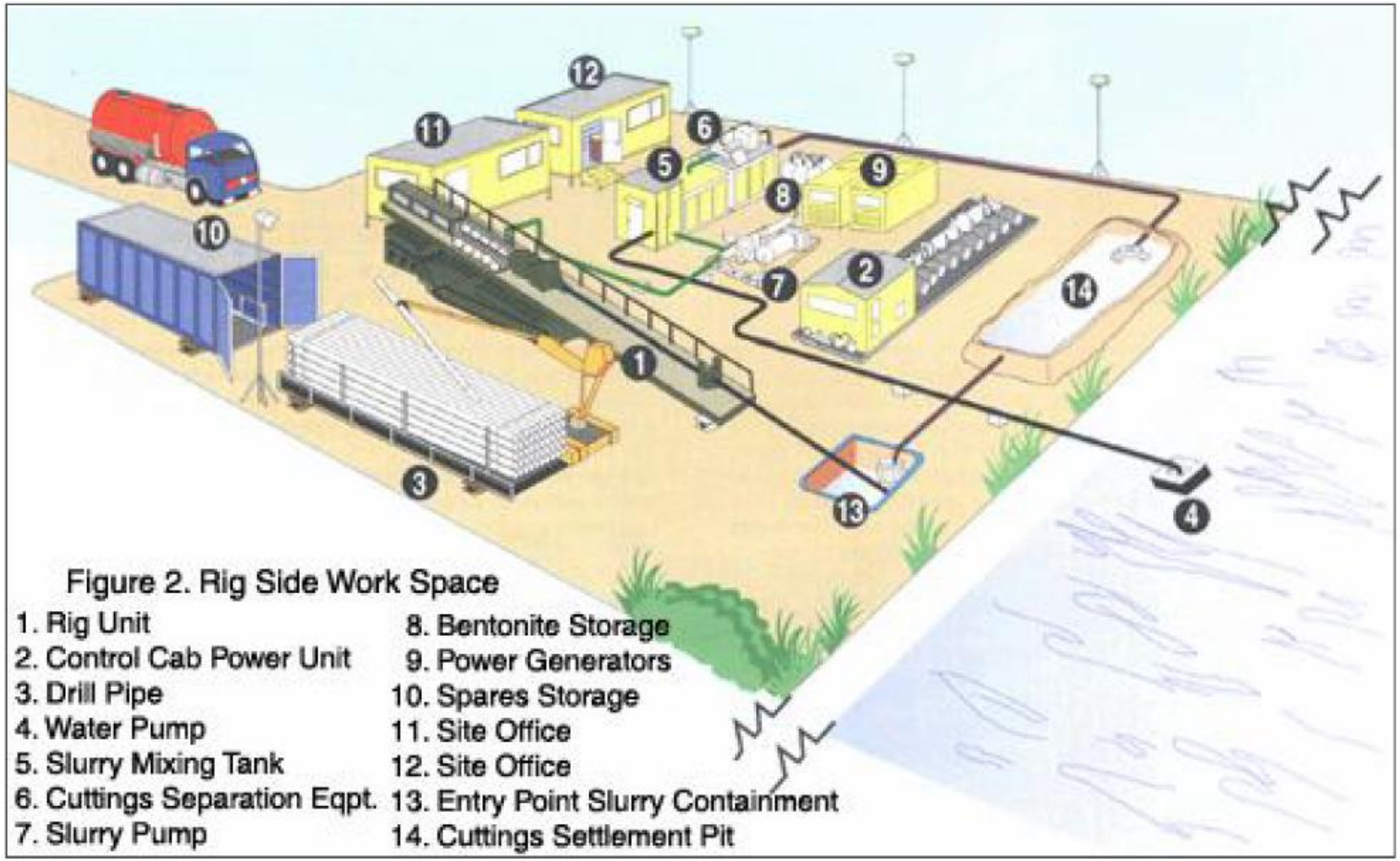
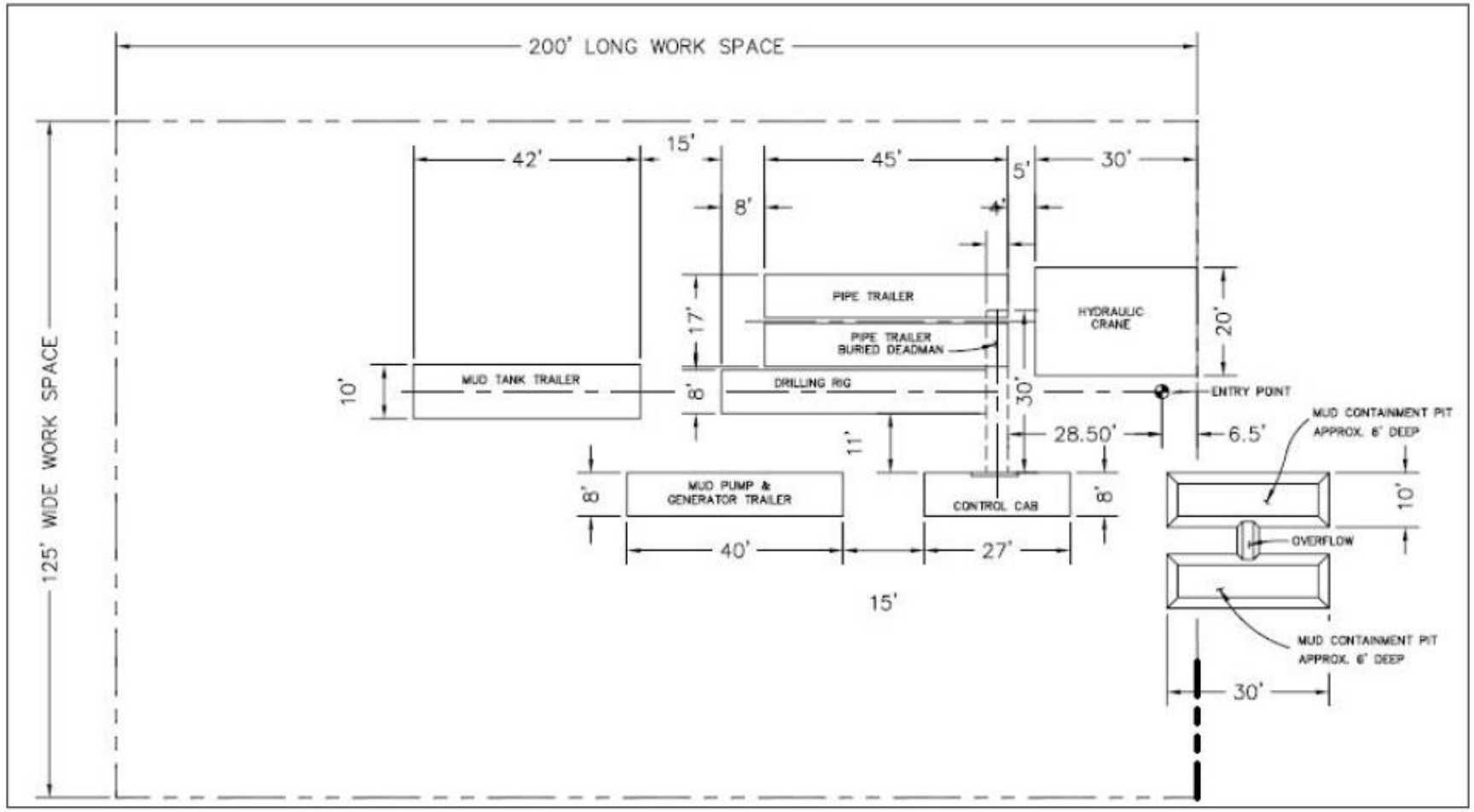


Figure 2. Rig Side Work Space

1. Rig Unit
2. Control Cab Power Unit
3. Drill Pipe
4. Water Pump
5. Slurry Mixing Tank
6. Cuttings Separation Eqpt.
7. Slurry Pump
8. Bentonite Storage
9. Power Generators
10. Spares Storage
11. Site Office
12. Site Office
13. Entry Point Slurry Containment
14. Cuttings Settlement Pit

Typical Drill Rig “Spread” or Set Up – Maxi-Rig



Hathaway Bridge Spread

Pipe Side Working Space

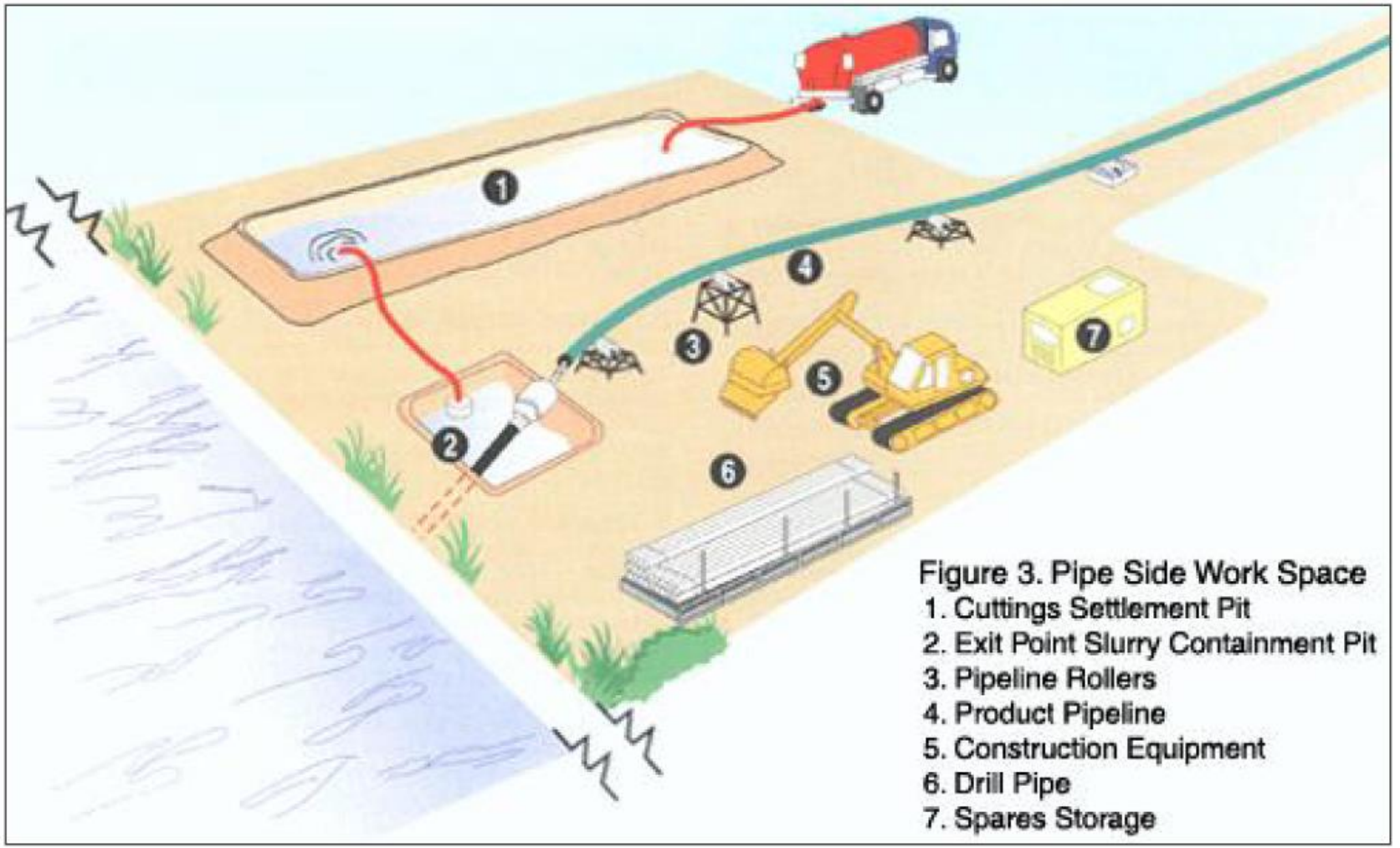


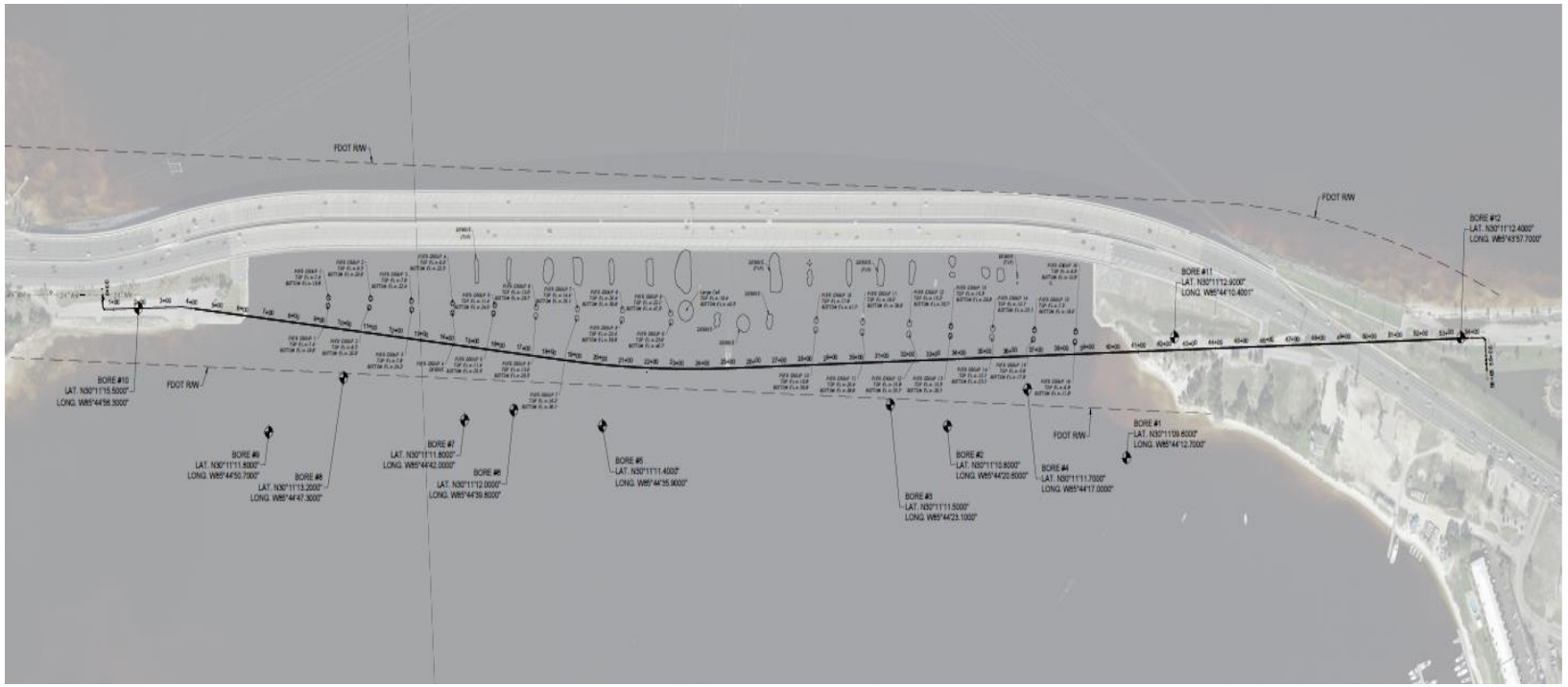
Figure 3. Pipe Side Work Space
1. Cuttings Settlement Pit
2. Exit Point Slurry Containment Pit
3. Pipeline Rollers
4. Product Pipeline
5. Construction Equipment
6. Drill Pipe
7. Spares Storage

Hathaway Bridge Pipe Side

Subsurface Investigation

- Geotechnical information is critical to overall success
- ~500 LF increments below elevation of planned depth
- N-values 10-50 are ideal
- Geological transitions present unique challenges
- Rock requires special tooling and increases cost 2.5-3X

Hathaway Subsurface Soil Boring Plan



- September 2018
- Primarily sands with varying amounts of silt, clay and shell
- 112’ depth identified as most suitable soils

Steering bits – how they work based on geology

- In softer ground, ‘spade’ or ‘spoon’ bits may be used

- In harder ground and rock, a down-hole “mud motor” with a “bent sub” to steer or rock hammer

- In all cases, drilling fluid is used to aid in the steering and ‘cutting’ of the soil

Reamer Selection based on Geotech

- Helical (S, CL, DC)
- Fluted (S, DC, Cobble)
- Wing / Bar Cutter (S, CL, DC)
- Spiral (Cobble)
- Radial Flow (S, CL, DC, Cobble)
- Fly Cutter (S, CL)
- Cyclone (S, CL)
- Hole Opener (Rock)

Hathaway Bridge Reamer Process

- 40” borehole (6”>24”>30”>40”)
- Trailed rods
- Reduction in mud density prior to pull-in with recycler
- XL Pull Head w/ Barrel Reamer in front pull-in

Drilling Fluid based on Geotech

Drilling Fluid Is:

- Primarily water
- Clay mineral (bentonite)
- Polymers
- Lost circulation materials
- Wetting agents
- Suspension aids
- lubricants

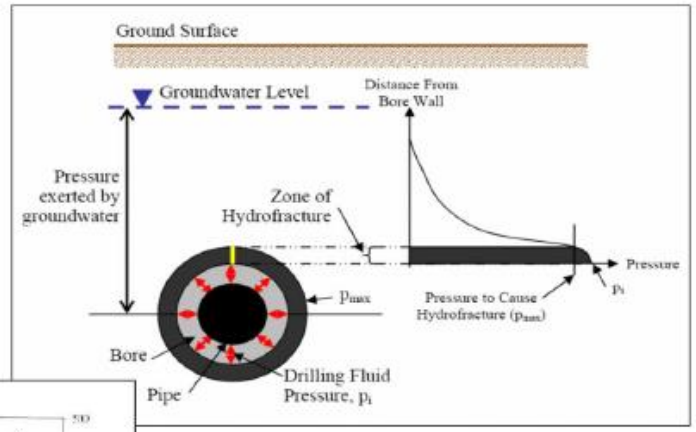
Drilling Fluid Must:

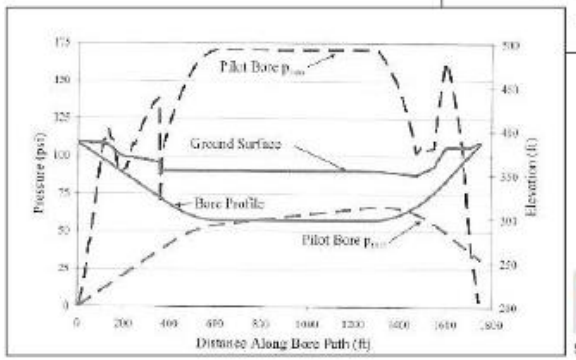
- Transport cuttings or spoils from the borehole
- Inhibit exfiltration of fluid from the borehole
- Lubricate the HDD tooling

MUD CONTROL

THERE IS NO UNIVERSAL SOIL, SO THERE CAN NOT BE A UNIVERSAL MUD MIXTURE AND VOLUME TO BE PUMPED

- Indicators of poor mud control
  - Loss of circulation
  - Frac out or inadvertent return
  - Low solids return rate
  - Soil sticking to drill stem
  - High fluid pumping pressures
  - High Pull Forces
  - High Rotational Torque
  - No additives to the makeup





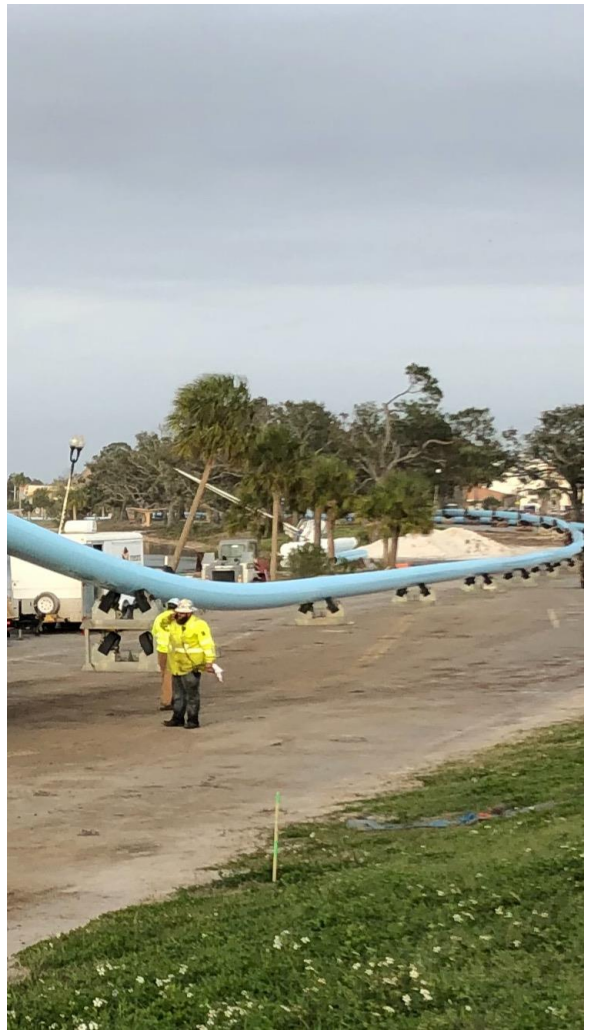
AEGION Stronger. Safer. Infrastructure.

Underground Solutions

Plastic Cavity Expansion Model is used to estimate geological pressure carrying capacity

Pre-qualifications and Driller Requirements

- Driller experience with HDDs of similar length and equipment
- Game Plan for Success
  - Drilling plan
    - Equipment and specifics of drill completion
  - Drilling Fluid Management Plan
  - Drill Contingency Plans
    - Spills, Inadvertent returns, product pipe issues, loss of returns or circulation



Hathaway Bridge Drilling Fluid

- Constant monitoring of drill fluid properties
- Drillplex drilling fluid system
  - Added to bentonite mix
  - Mixed metal oxide and water based
  - Highly viscous and non-toxic
  - Gel state when not circulating
  - Superior suspension and carry capacity
  - Improves hole stability

Drilling Fluid

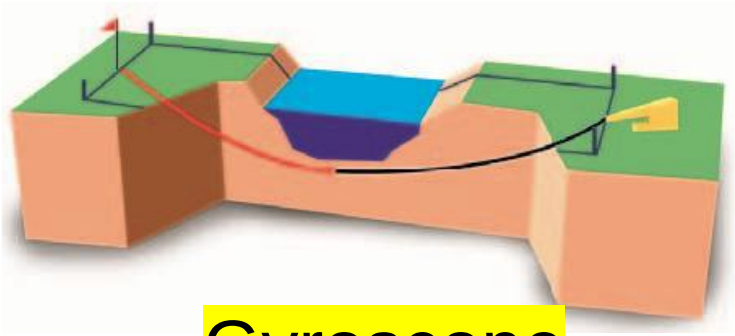
- Cleaned
- Reused
- Solidified
- Disposed of:
  - Landfill
  - Earthen pits
  - Land applied
  - Soil amendment
  - Ponds
  - Sometimes requires testing

Tracking Systems

- Walkover

- Electronic bore path logging available for all tracking

- Wireline



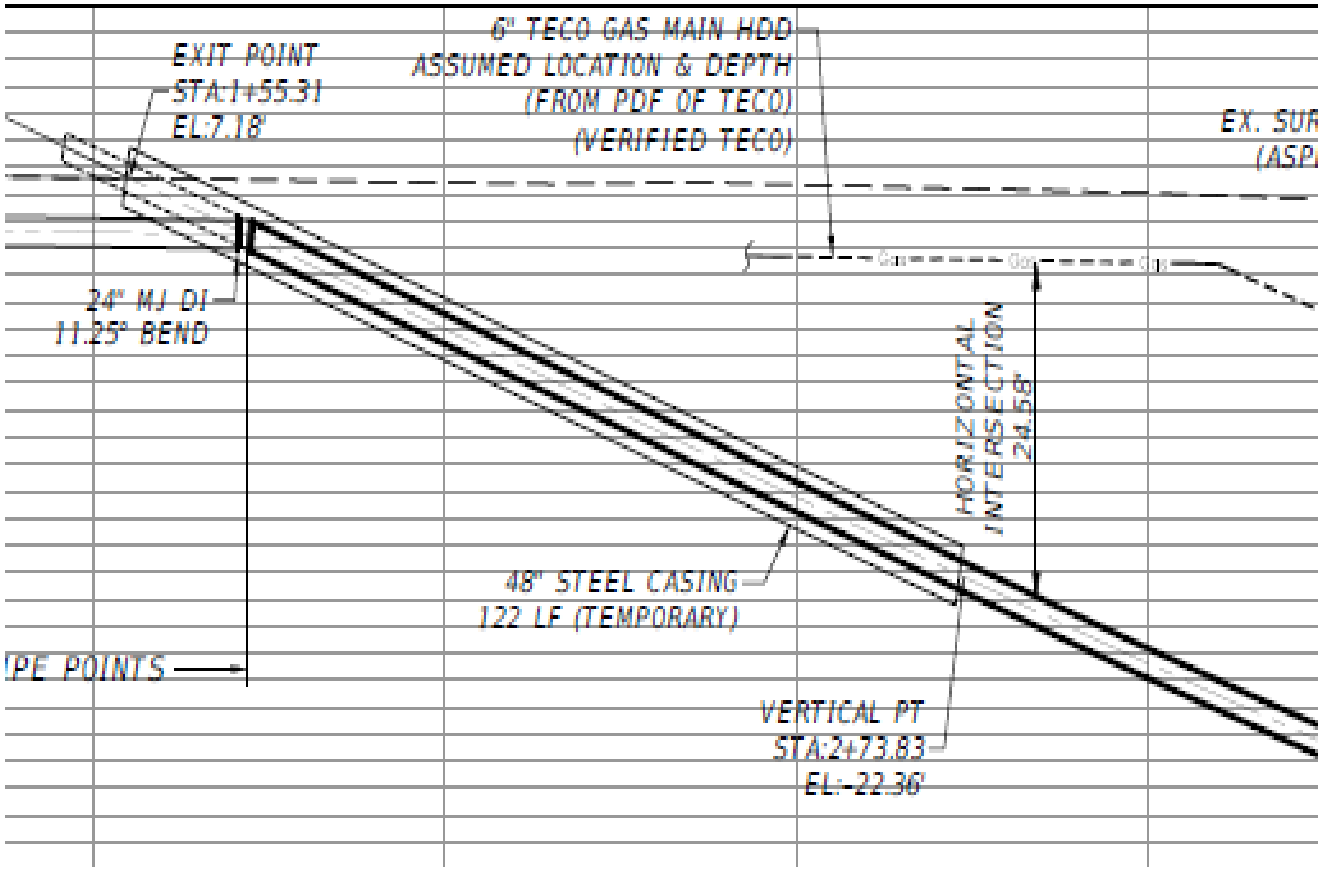
- Gyroscope

HDD Conductor Casings

- Prevents groundwater and sediment infiltration into borehole
- 80-200+ LF
- Stabilizes borehole and reduces risk of inadvertent returns
- Requires centralizers for drill pipe
- Reduces friction with carrier pipe
- Annular space can be grouted or casing pipe removed

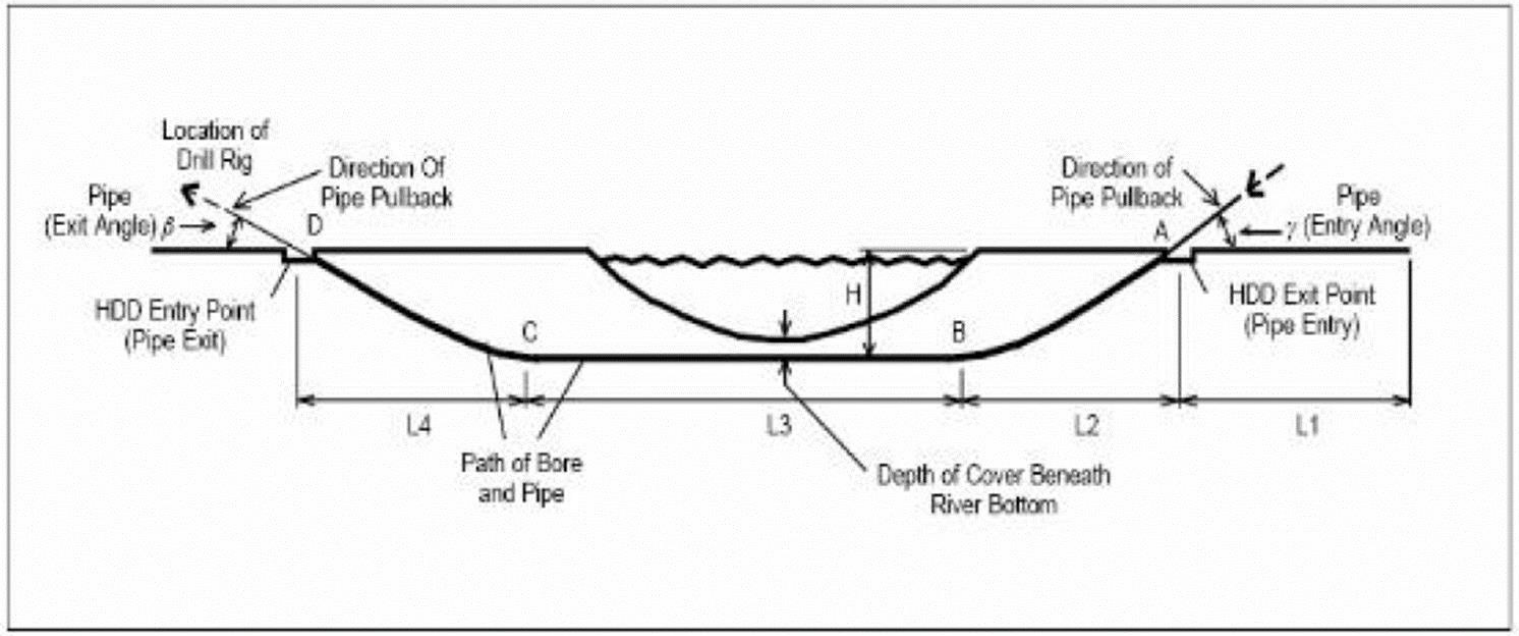
Drilling Fluid

- Air hammers utilized to install 48-inch steel casings at entry/exit points
- 122 ft on West side
- 171 ft on East side
- Steel casing annular space grouted with low-density cellular grout



Borehole Geometric Alignment Considerations

- Curves
- Couple alignment with geotechnical understanding
- Use Large Radii
- Keep alignments straight
- Avoid compound curves
- Appropriate offset from critical elements (rivers, roadways, other conflicts)



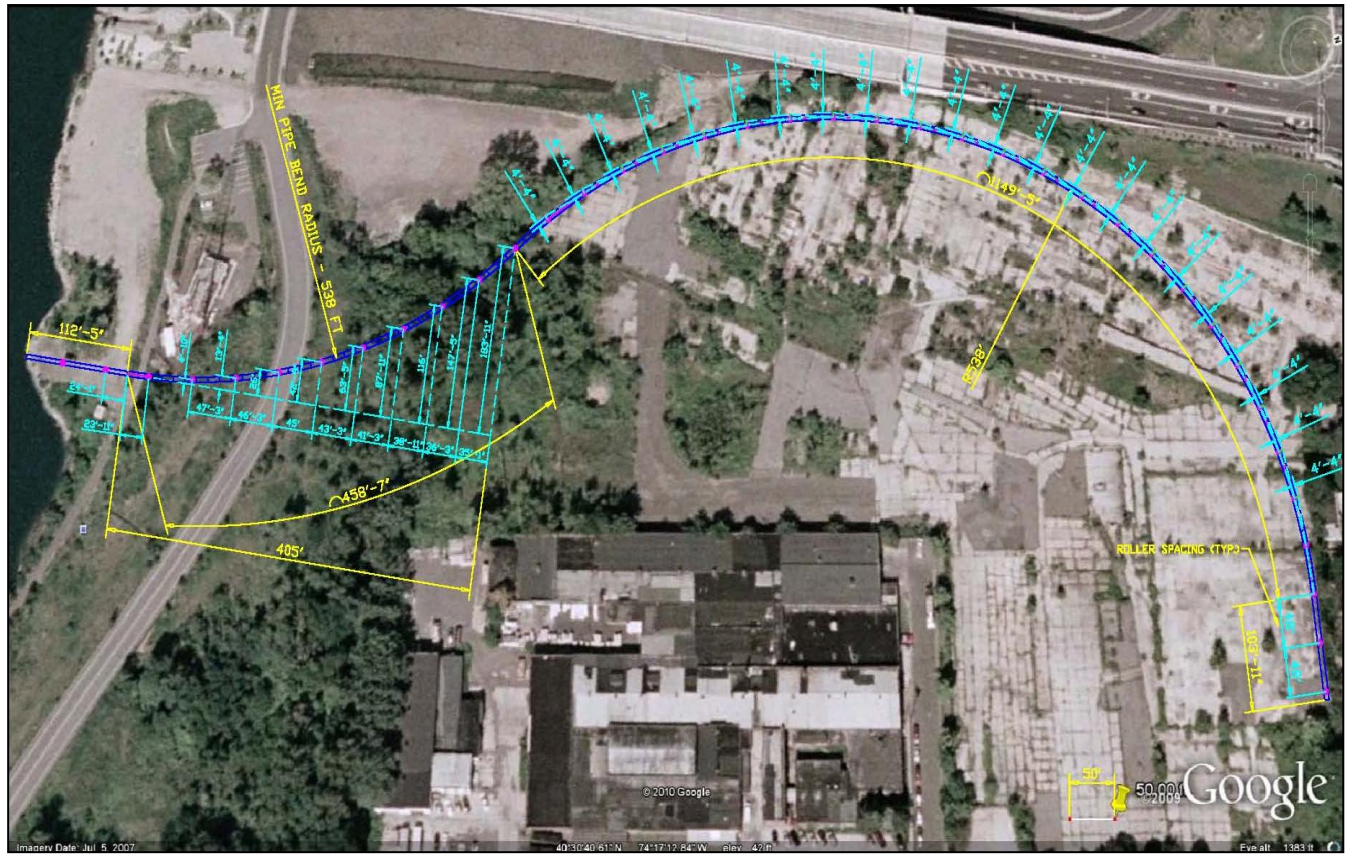
Hathaway Alignment Considerations & Design

- Old Bridge Structure
- Bathymetry
- 48’ deep water column
- 6” Teco Gas Main
- Geotech
- FDOT HWY 98 (10X Reamer)

- Exit Angle = 10 degrees
- Entry Angle = 14 degrees
- 3000’ radius vertical
- 2500’ horizontal curve
- 24” DR 18 FPVC = 538’ min radius
- 112’ depth

Surface Layout

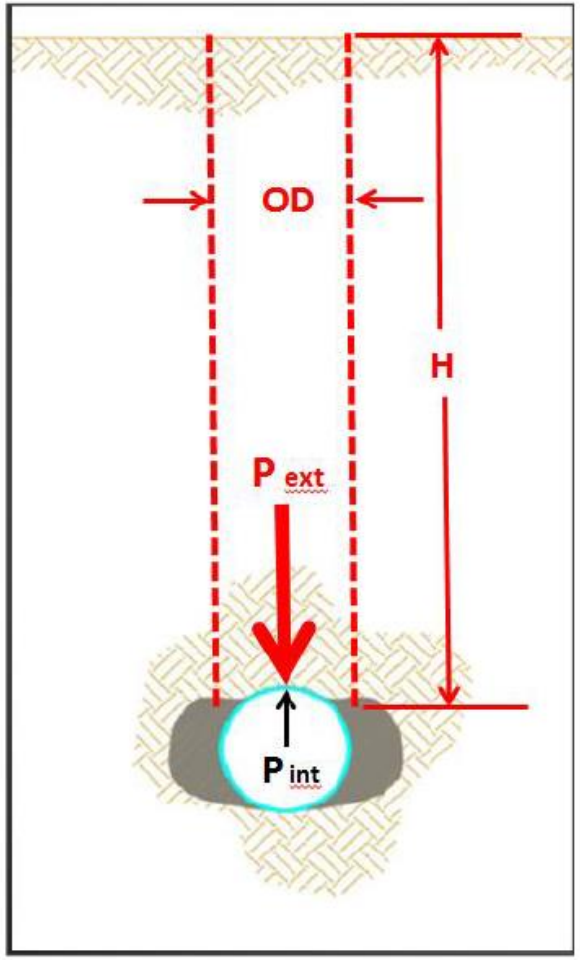
- Obstructions above ground interfere with entering pit
- Pipe string
- ROW Easements
- Overhead power
- Horizontal bending
- Vertical Bending



Hathaway Bridge Pipe Layout

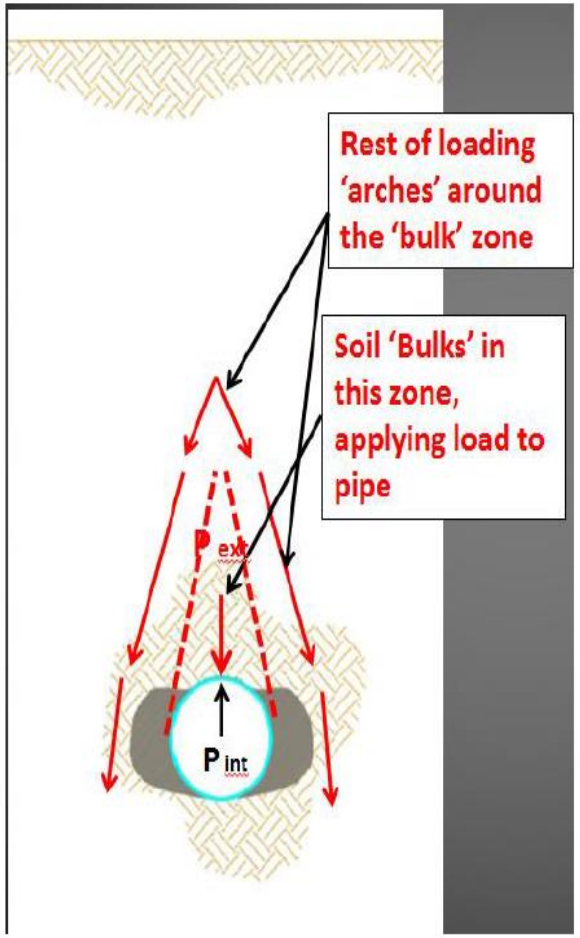
- Three separate 1,800-ft pipe strings on 1300’ radius
- Aerial insertion into pipe string provided by UGS
- 2 Intermediate fusion joints

Full Prism Loading



- Full soil prism assumed
- Loading calculated based on depth and OD of pipe
- Guidance in the PVC Pipe Handbook, ASTM F1962, other locations

Soil Bridging

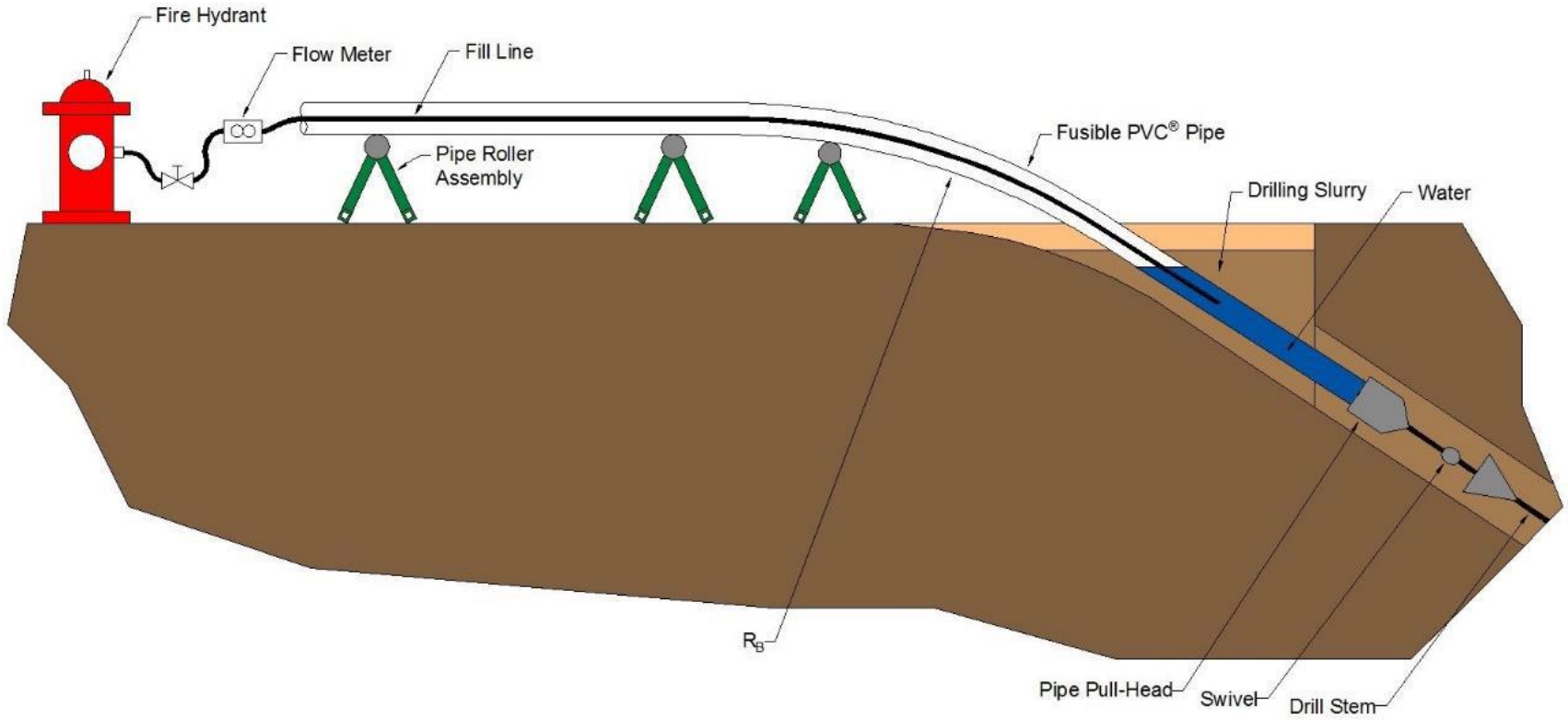


- Prism load is reduced by a % based on 'soil bridging'
- Overburden will 'bridge' over the excavation, thus reducing the effective load
- Guidance in ASTM F1962

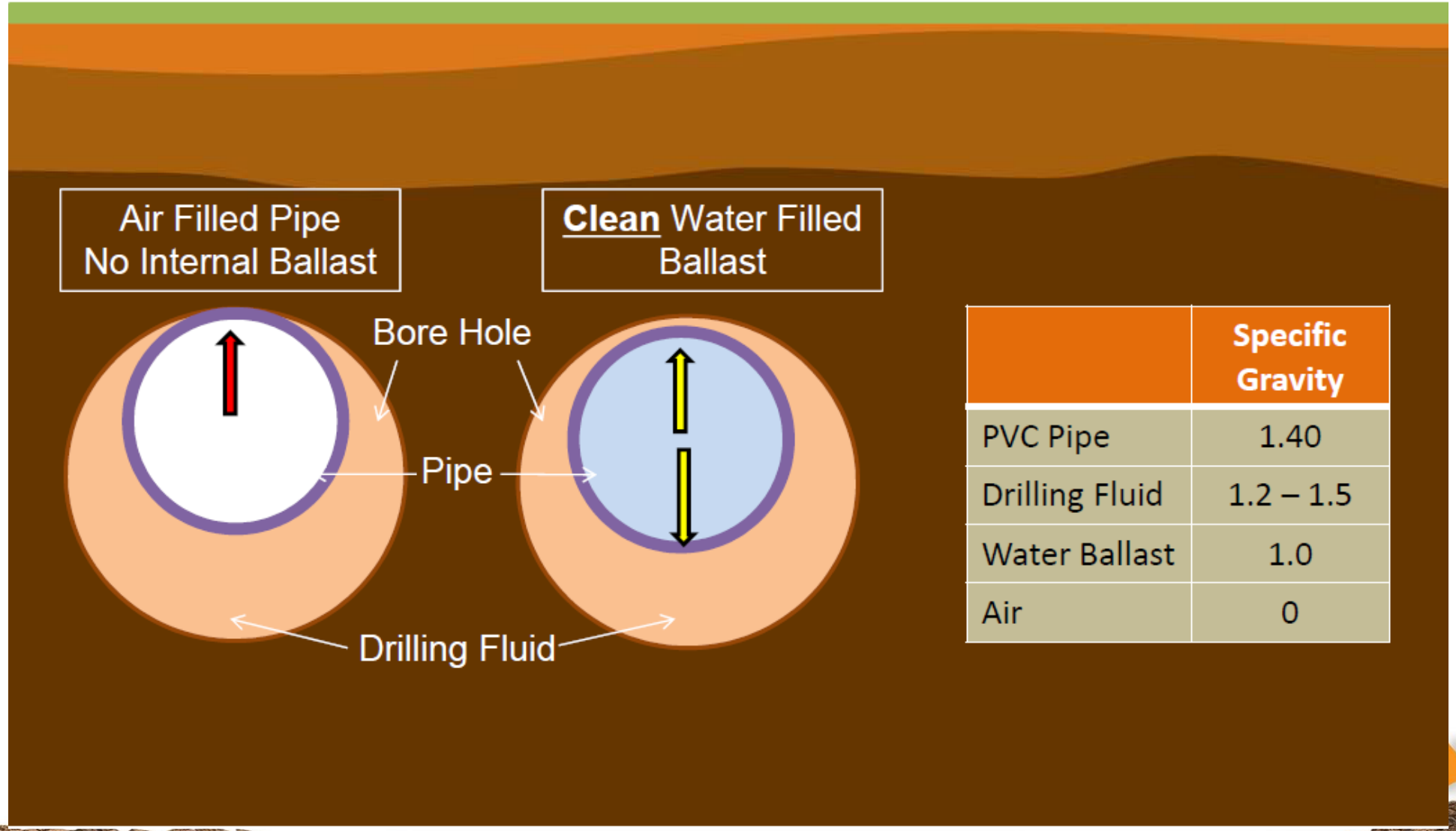
Critical Buckling Resistance is an Important Consideration for Installation and Long Life Expectancy (i.e. in HDD Borehole)

Long Term Critical Buckling Pressure			
PVC		HDPE	
Modulus = 400,000 psi		Modulus = 29,000 psi	
SF = 1.0		SF = 1.0	
DR	Critical Buckling Pressure (PSI)	DR	Critical Buckling Pressure (PSI)
DR 14	426	DR 7.3	291
DR 18	191	DR 9	142
DR 21	116	DR 11	73
DR 25	68	DR 13.5	37
DR 32.5	30	DR 17	18
DR 41	15	DR 21	9

Pipe Ballasting to reduce buoyancy

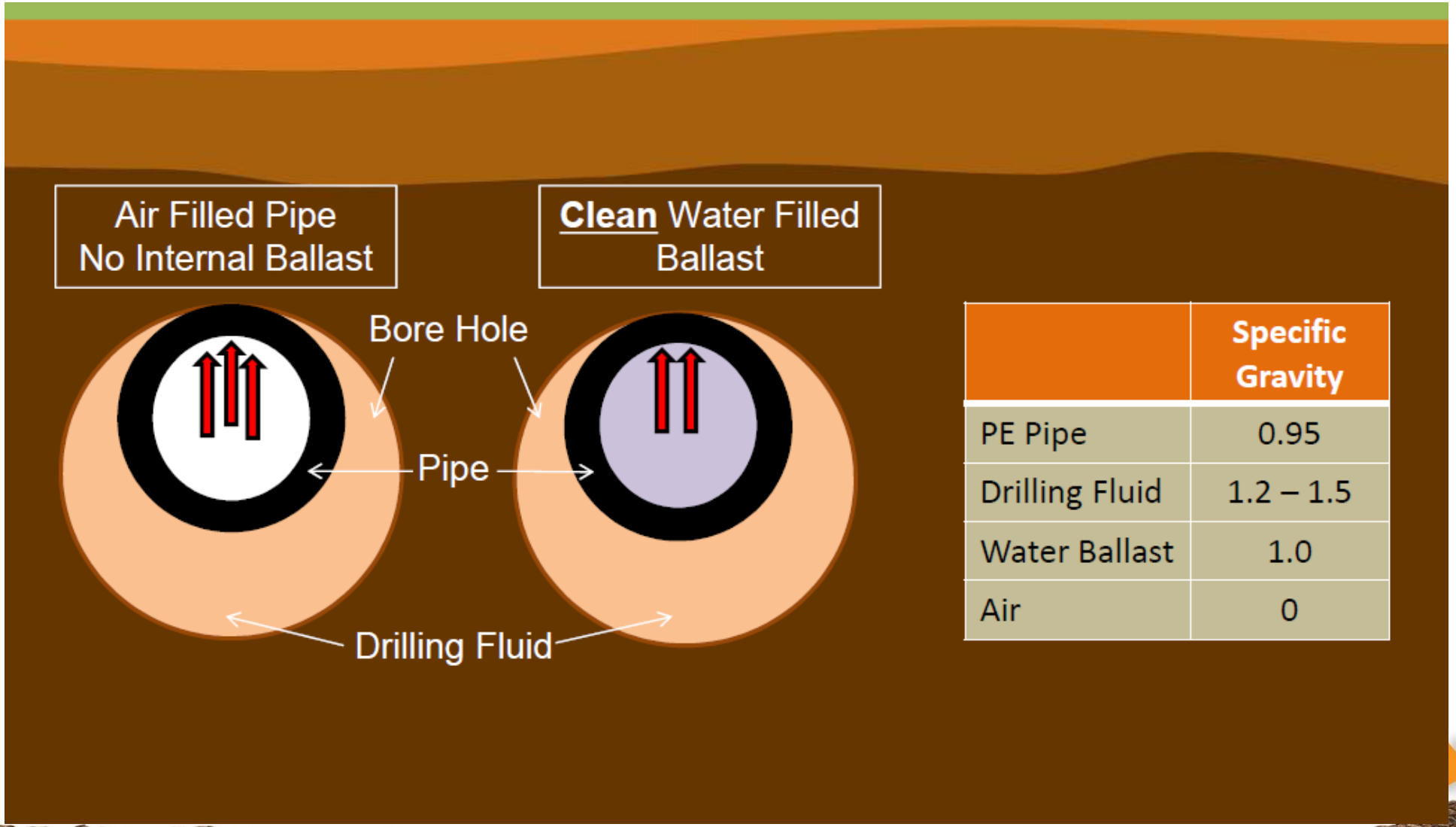


Buoyancy Example for PVC Pipe in HDD Bore Hole



	Specific Gravity
PVC Pipe	1.40
Drilling Fluid	1.2 – 1.5
Water Ballast	1.0
Air	0

Buoyancy Example HDPE Pipe in HDD Bore Hole



	Specific Gravity
PE Pipe	0.95
Drilling Fluid	1.2 – 1.5
Water Ballast	1.0
Air	0

Hathaway Pipe Ballast Setup

Buoyant Weight Component	If Pulled Empty #/LF	Ballasted #/LF (12.5#/gal)	Ballasted #/LF (10.7#/gal)
Displaced Drill Mud(3.63 CF/LF @93.6 pcf/12.5#/gal)	339	339	290
24” DR 18 Pipe Weight (per LF) 25.8” OD	(71)	(71)	(71)
Internal Ballast(2.86 CF.LF @62.4 pcf)	0	(179)	(179)
Total Buoyant Weight	268	89	50
Pull Force per LF using 0.3 COF	80.4	26.7	12
5,400 LF HDD Total Estimated Pull Force	434,000	144,180	64,800

24” DR 18 Fusible Pipe Fusion

- Pipe fused together using McElroy T-900 machine, and assembled in three separate 1,800-ft pipe strings
- Test plugs installed inside pipe
- Intermediate fusion on rollers
- Datalogger or 119 joints

Pipe Pull Info

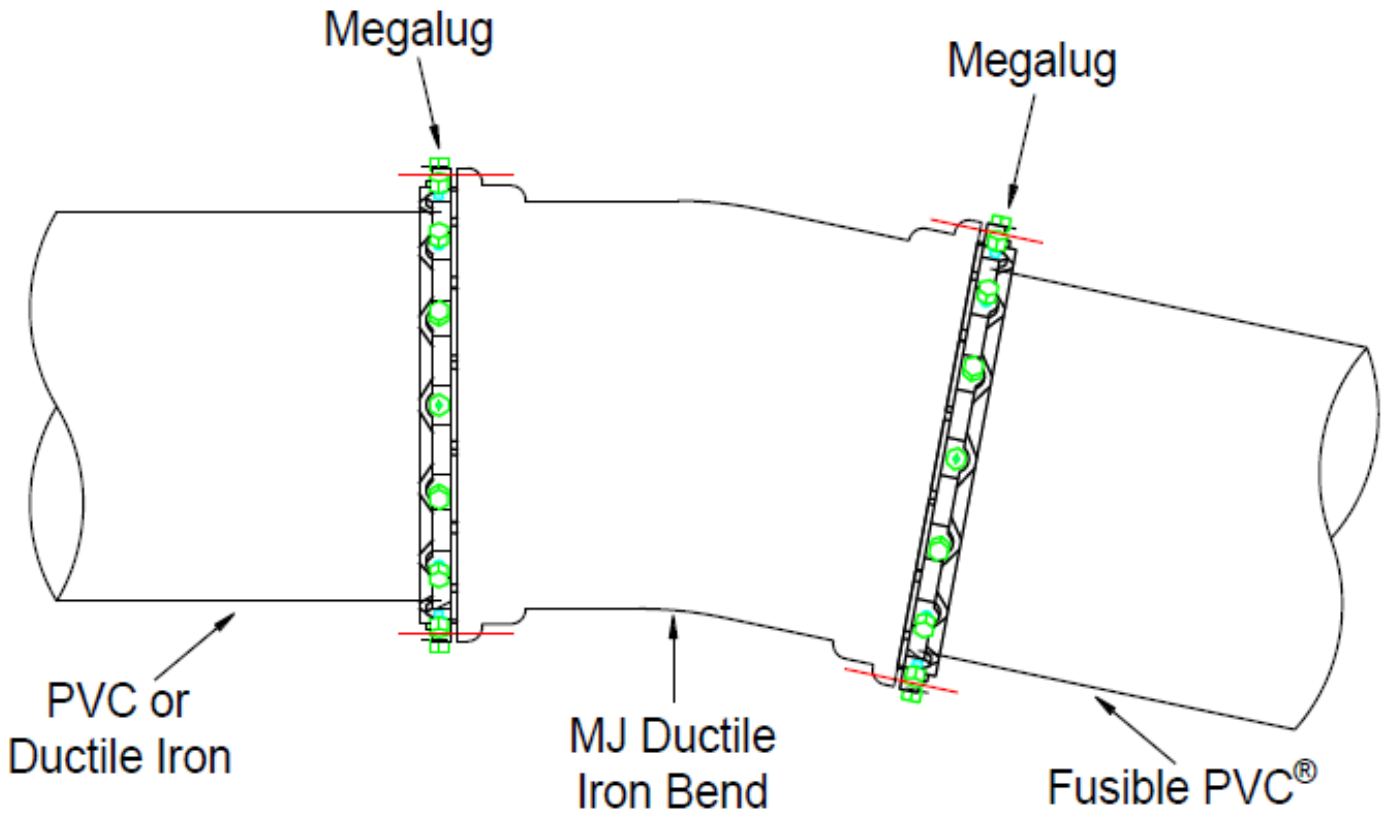
- **Total Length of HDD** = 5400 LF
- **Install Time** = 18 hours
- **24” DR 18 DIPS FPVCP** = 71.08 LBS/FT
- **Total weight of pipe string** = 383,832 LBS
- **Recommended Pull Force** = 307,000 LBS
- **Average Pull Forces per rod** = 56,500 LBS
- **Average Pull Forces over last 2000 LF** = 60,000 LBS
- **Highest pull force/rod** = 83K LBS

Construction – Pressure Test and Disinfection

- DI end caps with megalugs
- Marshall Brothers flushed the pipe for 3 full volumes of water to remove air from the pipe
- Pressure test performed for 2 hours @ 150 PSI (at the surface)
- Disinfected utilizing a chlorine solution
- New water main was connected to existing ductile iron main

Reconnection Details

Fusible PVC® Pipe Detail



Fusible PVC Advantages over HDPE pipe

- 2.4X safe pulling stress of HDPE pipe
- ~½ weight of HDPE pipe for larger sizes
- Standard fittings for reconnection and long-term maintenance
- Resistant to disinfectant oxidation
- No relaxation period
- Long term vertical loading pipe stiffness exceeds HDPE pipe
- Low failure rate
- Scratch and abrasive resistance with Rockwell hardness >2X HDPE pipe
- Buoyancy modification advantages due to SG

Welded Steel Pipe Advantages

- Strength to weight ratio
- Tensile Strength
- Distance capability
- Ability to impact (Use of “hammer”)

Fusible PVC Advantages over Steel in W/WW and conduit applications

- Corrosion resistant
- Tighter bend radius
- Less layout room required
- Assembly with data logged heat fusion versus welding
- Ability to de-bead remotely
- Reduced power cable ampacity loss
- Reconnection with standard fittings

Long Pulls List

- FPL Indian River - 7020 LF 30” FPVC Casing X 2
- Kiawah Island – 6980 LF 16” FPVC Water Main
- Paris Island – 6,400 LF 16” FPVC Force Main
- Pineda Causeway – 6,200 LF 16” FPVC Reclaim X 2*
- Padre Island – 5,545 LF 18” FPVC Water Main
- Padre Island - 5,535 LF 4” FPVC power
- Middlesex March Main – 5,400 LF 24” FPVC Water Main
- Hathaway Bridge – 5,400 LF 24” FPVC Water Main
- Lady’s Island – 5,335 LF 16” FPVC Force Main

5,400 LF 24” DR 18 Fusible C900 HDD Crossing

Questions?

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