HDD & DPI CROSSINGS

360° Solutions, from Inception to Completion

Presenters: Justin Taylor, P.Eng., P.E.
Travis McCartney
OUTLINE

COMPANY PROFILE
Who we are & What we do.

DESIGN PROCESS
From Preliminary Assessments through to Construction Completion.

GEOTECHNICAL INVESTIGATIONS
Identifying potential “show stoppers” which may have a major financial impact on construction.

CROSSING DESIGN
Detailed Design Process & Elements of Design.

ENVIRONMENTAL SUPPORT
Front End Planning, Drilling Fluid Disposal and Environmental Monitoring.

CONSTRUCTION
Management of on-site activities, construction data recording and reporting.
CCI Inc. is a leading expert in Horizontal Directional Drilling (HDD), Open-Cut and Micro-Tunneling methods. Since 2004, we have established ourselves as a driving force in the continued advancement of trenchless pipeline systems and employ proven methods for tackling difficult river crossings. CCI provides award winning, highly technical services to the pipeline, oil & gas and municipal infrastructure sectors including: Engineering Solutions, Construction Management, Environmental and Geotechnical Services, Forestry Planning & Reclamation Services.
Horizontal Directional Drilling (HDD) is a steerable trenchless method of installing underground pipe, conduit, or cables in a shallow arc along a prescribed bore path by using a surface-launched drilling rig, with minimal impact on the surrounding area.

SO WHAT IS HDD?
Direct Pipe Installation (DPI) is a steerable trenchless method of installing underground pipe in a shallow arc along a prescribed bore path by using a surface-launched Micro-Tunnel Boring Machine attached to the front of product pipe, in combination with a pipe thruster, with minimal impact on the surrounding area.
HDD vs. DPI

HDD:
• Product pipe layout on opposite side of HDD equipment
• Drilling fluid pressurizes borehole to return cuttings to surface
• Multiple ream passes/cleaning passes depending on final pipe size (oversized hole)
• Relatively Common / Lots of Contractors (Range of Skills)
• Generally lower cost per foot but generally longer
• Generally more water used and drilling fluid to dispose of

DIRECT PIPE:
• Product pipe layout on same side as Direct Pipe equipment
• Internal slurry lines return cuttings to surface
• Single pass installation, pipe is installed with the micro tunnel progression
• Higher cost per foot but may be much shorter due to shallow cover
• Limitations on length

HDD vs. DPI

**DIRECT PIPE:**
- Can be completed at shallow depth, regardless of entry/exit elevations
- Limits on maximum depth (3-4 bar; ~115' max depth)
- Can be utilized for 30” – 60” product pipe
- Optimal in sands, gravels, can do bedrock
- Upper limit 500m – 2000m (1600’ – 6500’)
- Smaller annular space but no excess cutting in the borehole so coating is normally protected (Abrasion coating still required)

**HDD:**
- Required depth is dependent upon elevations of entry/exit (Due to annular pressure – Hydraulic Head)
- Significant depth achievable if required (500’ +)
- Common for 1” up to 48” product pipe
- Optimal in clay, bedrock, dense / competent sands
- Upper limit ~2500m – 4000m (8200’ – 15000’)
- Higher annular space so coating may have less contact with borehole wall (Abrasion coating still required)
1. PIPELINE ROUTE/CROSSING EVALUATION
   Geotechnical, Environmental, Design & Construction Perspective

2. METHODOLOGY COMPARISON
   Cost & constructability: HDD, DPI, Slip-bore, Open-cut

3. GEOTECHNICAL INVESTIGATIONS

4. DETAILED DESIGN
   Pipeline & Crossings

5. REGULATORY APPLICATIONS & APPROVALS

6. CONSTRUCTION PLANNING
   Fluid disposal plans & construction specifications

7. CONTRACTOR SOURCING
   Tenders, evaluation, clarifications

8. CONSTRUCTION OVERSIGHT
   HDD & Environmental inspection
OBJECTIVES:

• Obtain sufficient surface and subsurface data to confirm trenchless feasibility, from a geotechnical perspective

• Create a realistic model of the ground conditions likely to be encountered along the length of the bore for use in trenchless design

• Reduce risk in the crossing design and construction

• Reduce the overall cost of the project

• Identify potential “show stoppers” which may have a major financial impact on construction;
  • thick gravel deposits
  • highly fractured bedrock
  • problematic groundwater (e.g. artesian conditions)
INVESTIGATION DELIVERABLES:

• Description of work, borehole logs and any other data collected
• Assessment of the overall feasibility of construction, from a geotechnical perspective
• Model of subsurface materials expected along the length of the bore and their general properties
• “No Drill Zone”
• Issues to be addressed in entry, exit and along the drill path

GEOTECHNICAL REPORT

Borehole logs summarize the data obtained from the field and lab testing, but...
INVESTIGATION DELIVERABLES:

- Description of work, borehole logs and any other data collected
- Assessment of the overall feasibility of construction, from a geotechnical perspective
- Model of subsurface materials expected along the length of the bore and their general properties
- “No Drill Zone”
- Issues to be addressed in entry, exit and along the drill path

• Should be read in conjunction with the report
FEASIBILITY & DESIGN
Typical Design Process includes:
• Drillpath Geometry & ROW Alignment
• Entry/exit angles, pad placement, layout, elevation
• Pipe Stress Analysis (installation & operation)
  • HDD / DPI
  • Pullback / Pipe Support
  • Buoyancy Control (HDD)
• Annular Pressure Analysis (HDD)
• Geotechnical information
ELEMENTS OF DESIGN

GEOMETRY & ROW/TWS

• **ROW & TWS Restrictions**
  • Pls, available pad TWS, adjacent infrastructure & obstacle

• **Elevation**
  • Low to high drill (AP & Fluid Management)

• **Entry & Exit Angles**
  • Limits of equipment and optimization

• **Pipe Layout TWS**
  • Available ROW or new TWS
  • Roping of pipe
  • Multiple pipe sections
ELEMENTS OF DESIGN

GEOMETRY & ROW/TWS

- ROW & TWS Restrictions
  - PIs, available pad TWS, adjacent infrastructure & obstacle
- Elevation
  - Low to high drill (AP & Fluid Management)
- Entry & Exit Angles
  - Limits of equipment and optimization

- Pipe Layout TWS
- Available ROW or new TWS
- Roping of pipe
- Multiple pipe sections
PIECE STRESS ANALYSIS

- ASME / ASTM / Pipeline Research Council Institute (PRCI)
- HDD may be Critical Stress Point of pipeline.
- Increased W.T. & grade
- Multiple cases to be considered: installation & operation
- Operation / hydrotest: similar to mainline analysis
- Installation: more difficult to calculate, may have multiple stages (prior-to vs. after pigging of buoyancy water)
- Product pipe is imparted with three dimensional strains or stresses during installation into HDD boreholes.

INSTALLATION LOADING

The main contributing strains / stresses include:

- Tension
- Bending Stress
- Hoop Stress
TENSILE STRESS

• Generally least critical installation stress component

• Tensile strength of most large diameter pipe far exceeds HDD rig pullforce capacity
PIPE STRESS ANALYSIS

TENSILE STRESS
• Generally least critical installation stress component
• Tensile strength of most large diameter pipe far exceeds HDD rig pullforce capacity

BENDING STRESS
• Bending Radius
  • Equipment steering capability, installation stress, and operating stress
  • Rule of Thumb – 1200 x OD (conservative or insufficient)
  • Allowable radius depends heavily on actual WT & grade
  • Design radius limited to % of allowable bending stress
  • Steering tolerances allow for variation, up to higher % of allowable bending stress
    • 1-joint (30’) / 3-joint / 10-joint average radii

HOOP STRESS
Primary Contributors:
• Depth
• Mud composition
• Sloughing soils
PIPE STRESS ANALYSIS

TENSILE STRESS
• Generally least critical installation stress component
• Tensile strength of most large diameter pipe far exceeds HDD rig pullforce capacity

BENDING STRESS
• Bending Radius
  • Equipment steering capability, installation stress, and operating stress
  • Rule of Thumb – 1200 x OD (conservative or insufficient)
  • Allowable radius depends heavily on actual WT & grade
  • Design radius limited to % of allowable bending stress
  • Steering tolerances allow for variation, up to higher % of allowable bending stress
    • 1-joint (30') / 3-joint / 10-joint average radii
PIPE STRESS ANALYSIS

TENSILE STRESS
- Generally least critical installation stress component
- Tensile strength of most large diameter pipe far exceeds HDD rig pullforce capacity

BENDING STRESS
- Bending Radius
  - Equipment steering capability, installation stress, and operating stress
  - Rule of Thumb – 1200 x OD (conservative or insufficient)
  - Allowable radius depends heavily on actual WT & grade
  - Design radius limited to % of allowable bending stress
  - Steering tolerances allow for variation, up to higher % of allowable bending stress
    - 1-joint (30’) / 3-joint / 10-joint average radii

HOOP STRESS
Primary Contributors:
- Depth
- Mud composition
- Sloughing soils

COMBINED STRESS
- Combined Stresses (Tensile/Bending/Hoop) can be well beyond allowable limits even when they are individually below their respective limits
- Critical stress: generally entry side build
PIPE STRESS ANALYSIS

TENSILE STRESS
- Generally least critical installation stress component
- Tensile strength of most large diameter pipes far exceeds HDD rig pullforce capacity

BENDING STRESS
- Bending Radius
  - Equipment steering capability, installation stress, and operating stress
  - Rule of Thumb – 1200 x OD (conservative)
  - Allowable radius depends heavily on actual WT & grade
  - Design radius limited to % of allowable bending stress
  - Steering tolerances allow for variation, up to higher % of allowable bending stress
    - 1-joint (30') / 3-joint / 10-joint average

HOOP STRESS
Primary Contributors:
- Depth
- Mud composition
- Sloughing soils
INSTALLATION PULLFORCE

RIG / THRUSTER SIZING

• High to low installations (fluid levels)
• Pullback slopes & drill pipe weight
• Buoyancy control
INSTALLATION PULLFORCE

RIG / THRUSTER SIZING
• High to low installations (fluid levels)
• Pullback slopes & drill pipe weight
• Buoyancy control

PULL HEAD DESIGN
• Heads engineered and rated for expected installation loads
INSTALLATION PULLFORCE

RIG / THRUSTER SIZING

• High to low installations (fluid levels)
• Pullback slopes & drill pipe weight
• Buoyancy control

PULL HEAD DESIGN

• Heads engineered and rated for expected installation loads

PIPE SUPPORT DESIGN

• Proper equipment spacing & heights
• Allowable pipe stress
• Equipment loading capabilities
INSTALLATION PULLFORCE

RIG / THRUSTER SIZING
• High to low installations (fluid levels)
• Pullback slopes & drill pipe weight
• Buoyancy control

PULL HEAD DESIGN
• Heads engineered and rated for expected installation loads

PIPE SUPPORT DESIGN
• Proper equipment spacing & heights
• Allowable pipe stress
• Equipment loading capabilities
ANULAR PRESSURE ANALYSIS

DRILL PATH LARGELY BASED ON AP ANALYSIS

2 Components:
- Expected drilling pressures
- Expected overburden or containing pressures
ANULAR PRESSURE ANALYSIS

DRILL PATH LARGELY BASED ON AP ANALYSIS

2 Components:
- Expected drilling pressures
- Expected overburden or containing pressures

DRILLING PRESSURE
- BHA size (pilot hole OD)
- Drill pipe OD
- Fluid pump rate
- Drilling methodology
ANULAR PRESSURE ANALYSIS

DRILL PATH LARGELY BASED ON AP ANALYSIS

2 Components:
- Expected drilling pressures
- Expected overburden or containing pressures

OVERBURDEN/CONTAINMENT PRESSURE

- Material
- Condition of material

DRILLING PRESSURE

- BHA size (pilot hole OD)
- Drill pipe OD
- Fluid pump rate
- Drilling methodology
CALCULATING ANNULAR PRESSURE

CONTAINMENT PRESSURE:
- Overburden Method or Cavity Expansion method based on the material and the condition of the material.

DRILLING PRESSURE:
- BHA size (Pilot hole OD)
- Drill pipe OD
- Fluid pump rate
- Drilling methodology
• Modelling drilling pressures:
  • Hydrostatic pressure
  • Bingham Plastic Fluid Model / Herschel Bulkley /Power Law
  • General overburden
  • Cavity Expansion / Delft Equation
• Safety factors and applicability of models based on experience, historical data, location, and regulatory requirements
• Factors utilized in models can evolve as construction data is received
  • Significant variances in AP analysis from different sources

Currently, our Rp, max is calculated based on soil/bedrock properties
A comparison showing the difference in hydraulic fracture pressures. Very stiff CL-CI clay at 30m (98') depth.
BH diameter = .31m (12.25”)

\[ P_{\text{max}} = \frac{R_p}{R_{\text{p, max}}} \left( \sqrt{\frac{R_p}{R_{\text{p, max}}}} \right)^2 + \left( \frac{\sigma_0 \cdot \sin \varphi + c \cdot \cos \varphi}{G} \right) - \frac{\sin \varphi}{1 + \sin \varphi} - c \cdot \cot \varphi \]
ANULAR PRESSURE ANALYSIS

• Modelling drilling pressures:
  - Hydrostatic pressure
  - Bingham Plastic Fluid Model / Herschel Bulkley / Power Law
  - General overburden
  - Cavity Expansion / Delft Equation
• Safety factors and applicability of models based on experience, historical data, location, and regulatory requirements
• Factors utilized in models can evolve as construction data is received

CALCULATING AP CONTAINMENT PRESSURE

Currently, our Rp, max is calculated based on soil/bedrock properties
A comparison showing the difference in hydraulic fracture pressures. Very stiff CL - CI clay at 30m (98') depth.
BH diameter = .31m (12.25")

\[ P_{\text{max}} = \frac{\sigma_0}{2} \left( 1 + \sin \varphi + \frac{c \cdot \cos \varphi + c \cdot \cot \varphi}{g} \right) \frac{- \sin \varphi}{1 + \sin \varphi} - c \cdot \cot \varphi \]

---

**Graph 1:**
- Plot showing Rp,max (m) vs. Depth of Cover (m)
- Data points:
  - \(Rp,\text{max} = H\)
  - \(Rp,\text{max} = 2/3H\)
  - \(Rp,\text{max} = 1/2H\)
  - Actual \(Rp,\text{max}\)

**Graph 2:**
- Hydraulic Fracture Pressure as a function of Rp, max (depth = 30 m)
- \(P_{\text{max}} = H/2\)
- Modified \(P_{\text{max}}\)
TRADITIONAL DELFT USAGE VS. MOD. DELFT USAGE

Delft Equation using $R_p, \max$ as $H^{1/2}$ (Standard)

Delft Equation using CCI derived $R_p, \max$ (CCI)
ANULAR PRESSURE ANALYSIS

CASE STUDY

ATHABASCA RIVER
ANULAR PRESSURE ANALYSIS

CASE STUDY

ATHABASCA RIVER

Unmodified Delft AP Chart

Modified Delft AP Chart
WATER QUALITY MONITORING

- Regulatory planning
- Water quality monitoring plan
- Install equipment and monitor turbidity
- Liaise with construction personnel
- Daily reporting
DRILLING WASTE DISPOSAL

DRILLING WASTE DISPOSAL OPTIONS

• Landspreading
• Landspray-While-Drilling (LWD)
• Mix-Bury-Cover
• Waste Management Facility
WHAT IS THE ROLE OF THE INSPECTOR?

- Maintain contract terms between contractor(s) and owner
- Ensure contractor is in compliance with engineered specifications
- Following proper drilling practices to reduce schedule and environmental risks
- Ensuring the contractor is following health and safety regulations and performing tasks within owners regulations
- Maintain communications between HDD contractor, owner and pipeline contractor to ensure deliverables are met
- Track costs and help with third party services where required
- Help with tooling selection where required
- Be the overall eyes and ears on site for the owner. Advise of any current or potential issues
QUESTIONS?
COLLABORATION.
COMMITMENT.
INNOVATION.