HDD & DPI CROSSINGS

360°Solutions, from Inception to Completion

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OUTLINE

COMPANY PROFILE
Who we are & What we do.

CROSSING DESIGN
Detailed Design Process & Elements of Design.

DESIGN PROCESS
From Preliminary Assessments through to Construction Completion.

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

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

CONSTRUCTION
Management of on-site activities, construction data recording and reporting.

WHAT WE DO

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.

SO WHAT IS HDD?

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 DIRECT PIPE?

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

Images courtesy of Herrenknecht. Retrieved from https://www.herrenknecht.com/en/products/productdetail

HDD vs. DPI

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)

DIRECT PIPE:

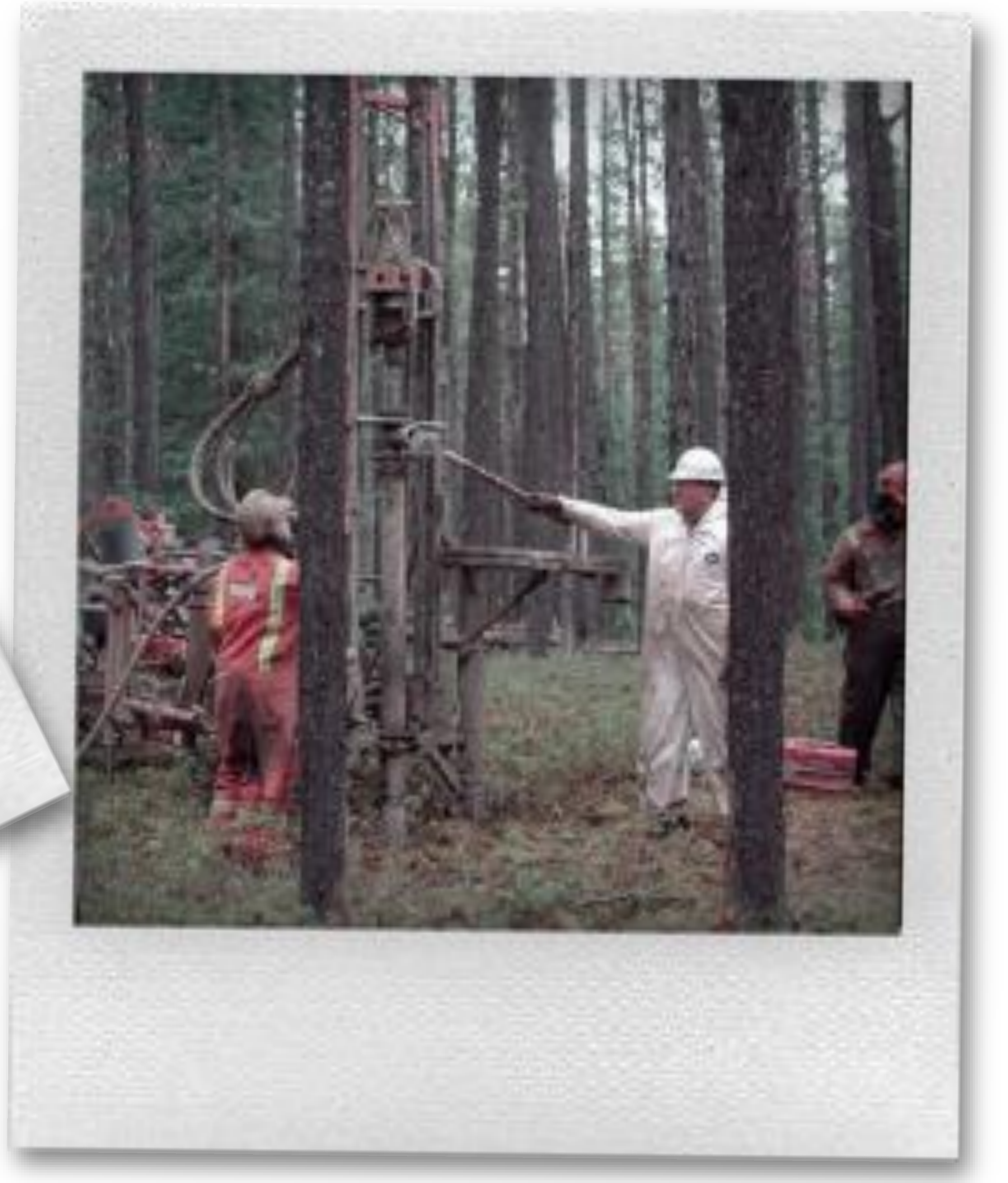
- Can be completed at shallow depth, regardless of entry/exit elevations
- Limits on maximum depth (3-4 bar; ~115' max depth)
- Can be utilized for 30" – 60" product pipe
- Optimal in sands, gravels, can do bedrock
- Upper limit 500m – 2000m (1600' – 6500')
- Smaller annular space but no excess cutting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

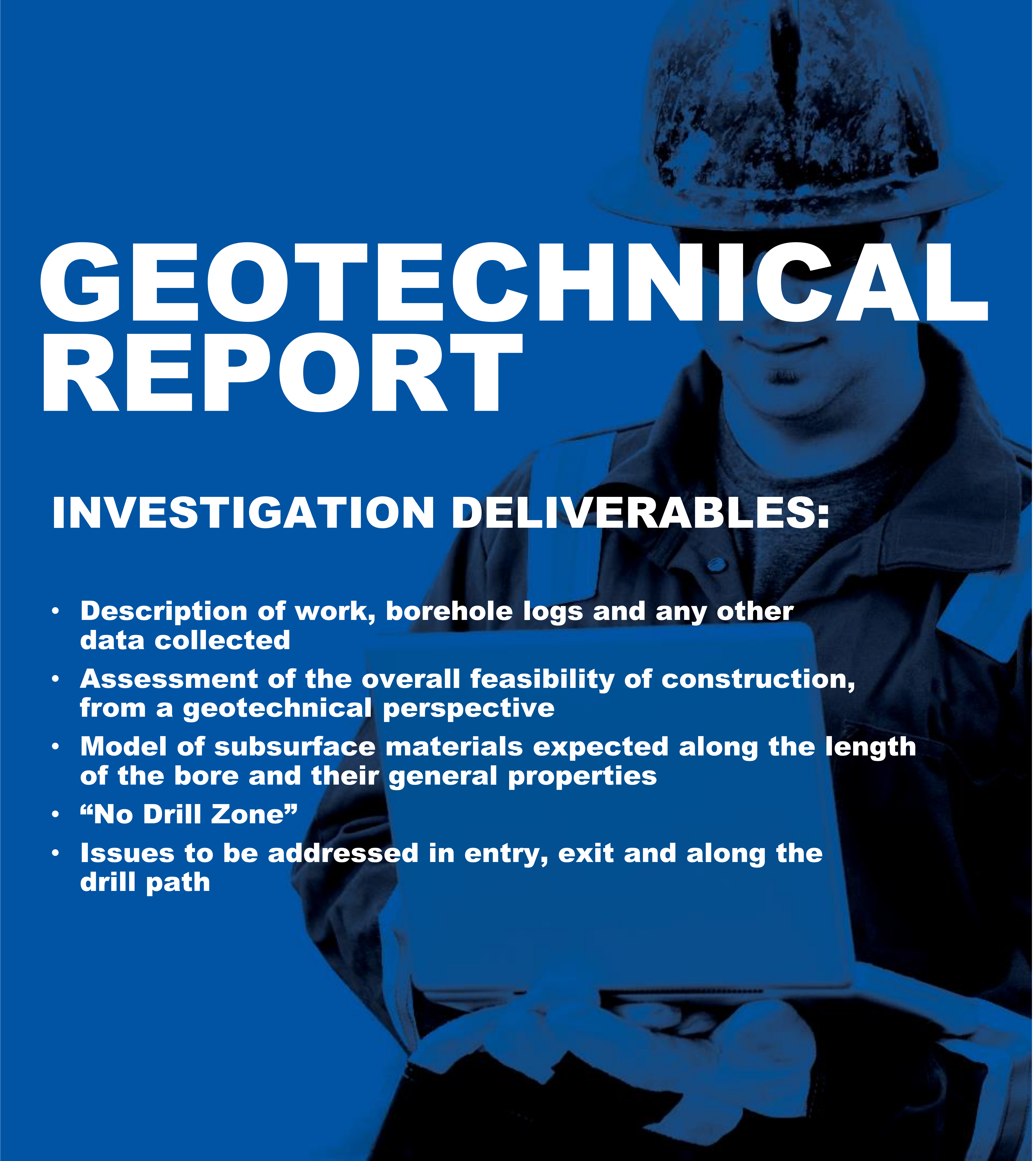

1
PIPELINE ROUTE/ CROSSING EVALUATION
Geotechnical, Environmental, Design & Construction Perspective
2
METHODOLOGY COMPARISON
Cost & constructability: HDD, DPI, Slip-bore, Open-cut
3
GEOTECHNICAL INVESTIGATIONS
4
DETAILED DESIGN
Pipeline & Crossings
5
REGULATORY APPLICATIONS & APPROVALS
6
CONSTRUCTION PLANNING
Fluid disposal plans & construction specifications
7
CONTRACTOR SOURCING
Tenders, evaluation, clarifications
8
CONSTRUCTION OVERSIGHT
HDD & Environmental inspection

GEOTECHNICAL INVESTIGATIONS

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)



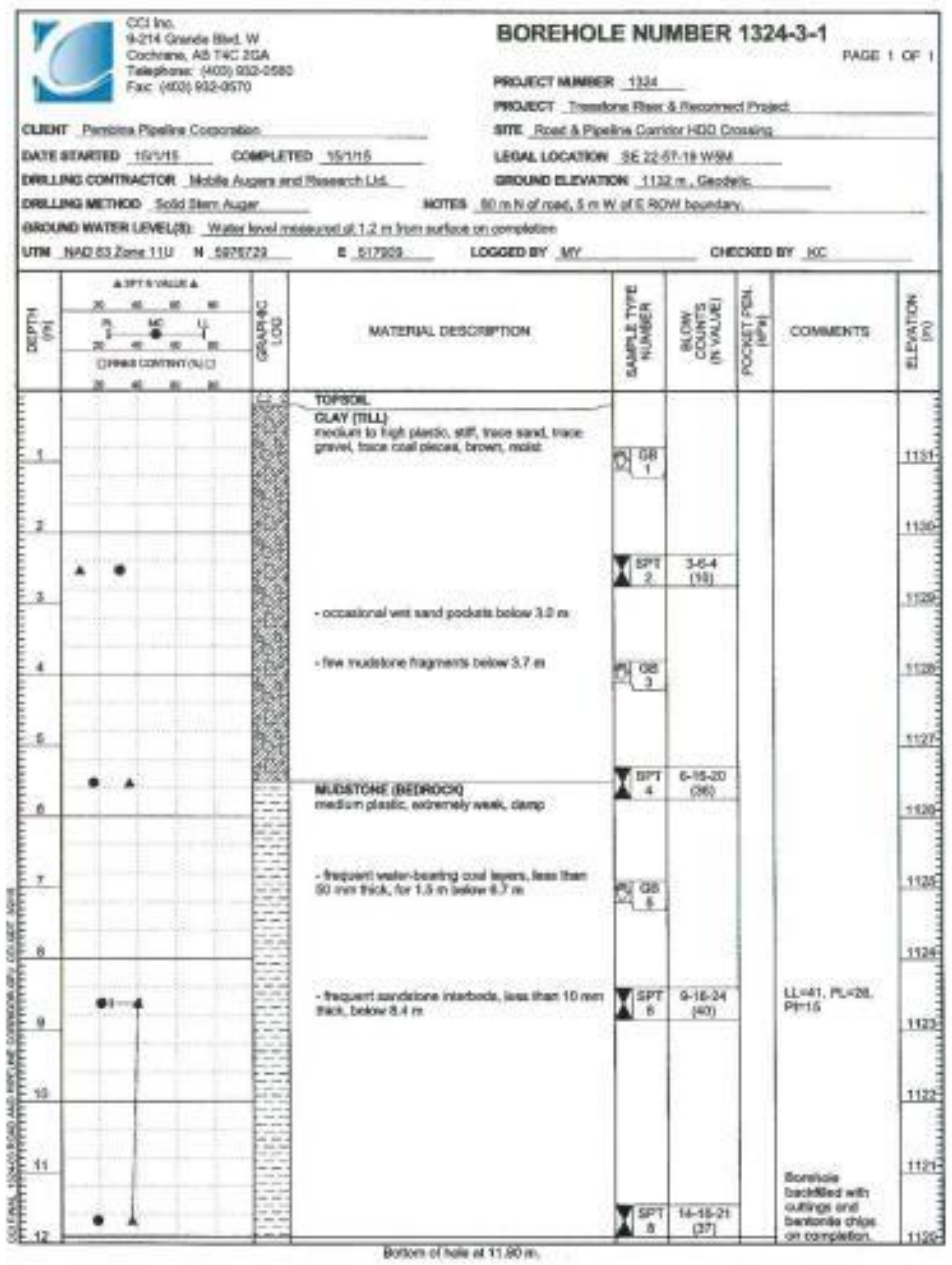


GEOTECHNICAL REPORT

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**

- **Borehole logs summarize the data obtained from the field and lab testing, but…**



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BOREHOLE NUMBER 1324-3-1

PAGE 1 OF 1

PROJECT NUMBER 1324
PROJECT Tresstone Riser & Reconnect Project
CLIENT Pembina Pipeline Corporation
SITE Road & Pipeline Corridor HDD Crossing
DATE STARTED 15/1/15 COMPLETED 15/1/15
LEGAL LOCATION SE 22-57-19 W5M
DRILLING CONTRACTOR Mobile Augers and Research Ltd.
GROUND ELEVATION 1132 m , Geodetic
DRILLING METHOD Solid Stem Auger
NOTES 50 m N of road, 5 m W of E ROW boundary.
GROUND WATER LEVEL(S): Water level measured at 1.2 m from surface on completion
UTM NAD 83 Zone 11U N 5976729 E 517909 LOGGED BY MY CHECKED BY KC

DEPTH (m)	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	BLOW COUNTS (N VALUE)	POCKET PEN. (kPa)	COMMENTS	ELEVATION (m)
			TOPSOIL					
			CLAY (TILL) medium to high plastic, stiff, trace sand, trace gravel, trace coal pieces, brown, moist					
1				GB 1				1131
2								1130
				SPT 2	3-6-4 (10)			
3			- occasional wet sand pockets below 3.0 m					1129
4			- few mudstone fragments below 3.7 m	GB 3				1128
5								1127
			MUDSTONE (BEDROCK) medium plastic, extremely weak, damp	SPT 4	6-16-20 (36)			
6								1126
7			- frequent water-bearing coal layers, less than 50 mm thick, for 1.5 m below 6.7 m	GB 5				1125
8								1124
			- frequent sandstone interbeds, less than 10 mm thick, below 8.4 m	SPT 6	9-16-24 (40)		LL=41, PL=26, PI=15	
9								1123
10								1122
11								1121
				SPT 8	14-16-21 (37)		Borehole backfilled with cuttings and bentonite chips on completion.	
12								1120

Bottom of hole at 11.80 m.

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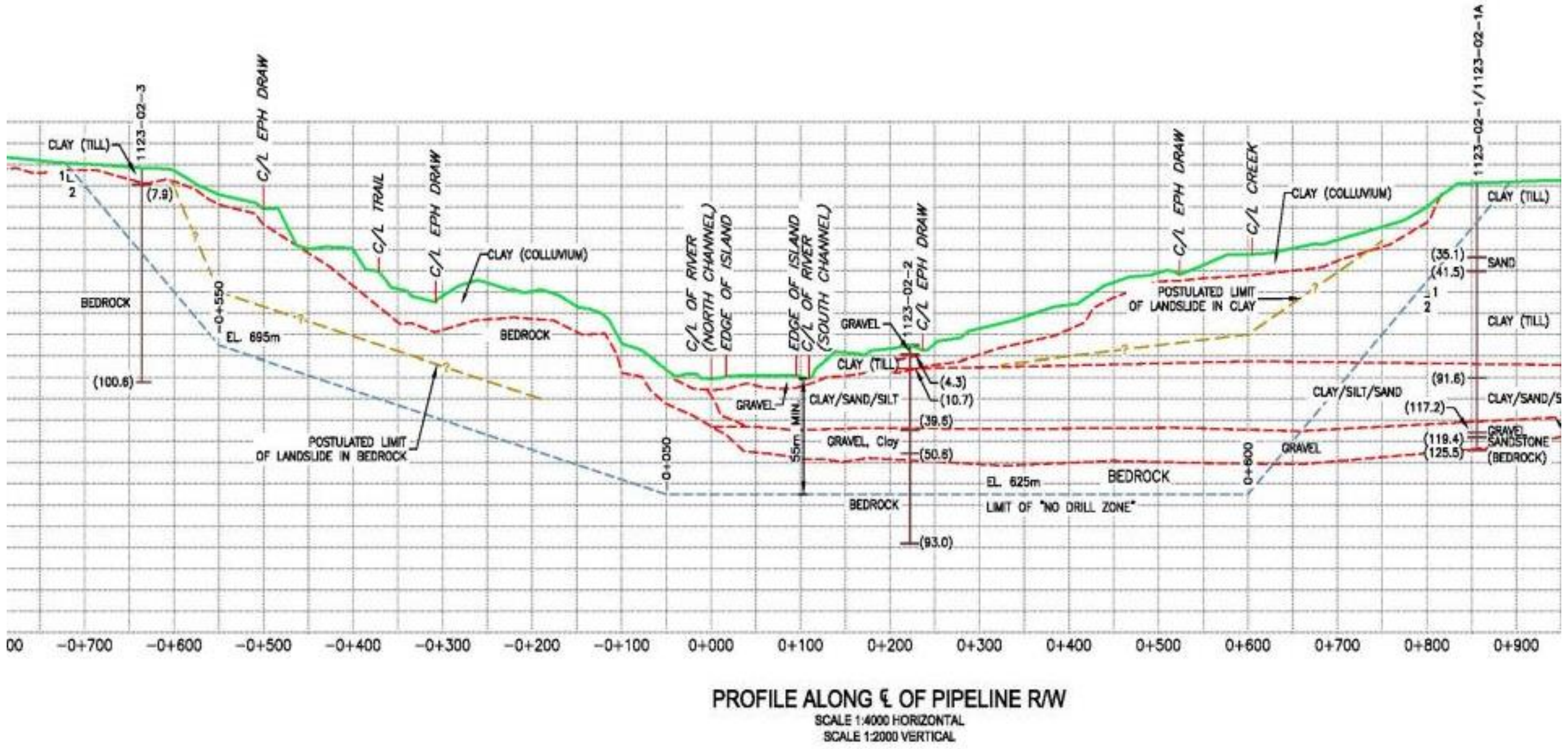
- Should be read in conjunction with the report



TRENCHLESS ENGINEERING

FEASIBILTY & DESIGN

Typical Design Process includes:

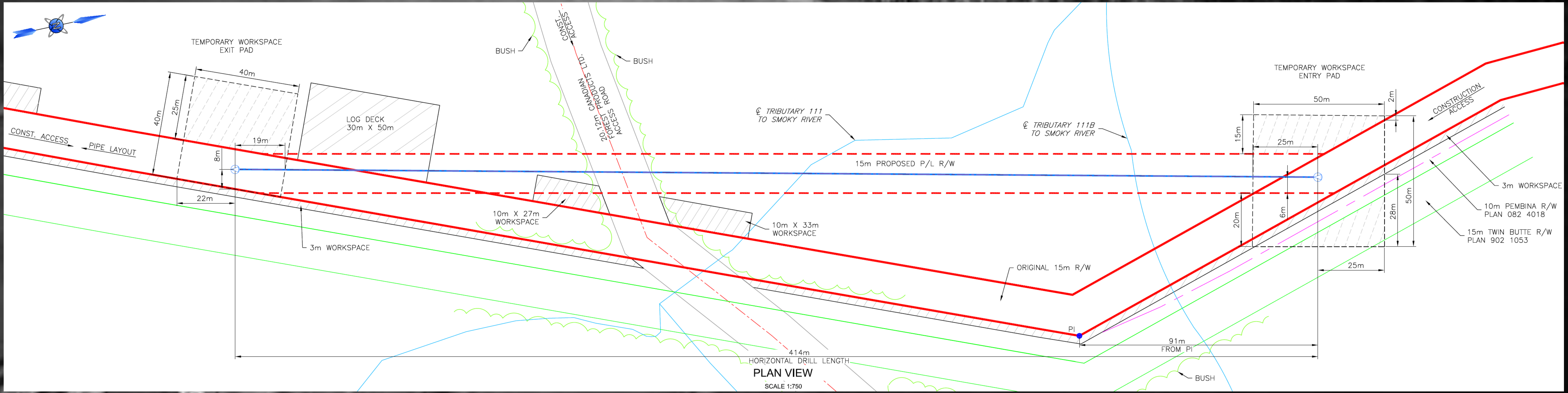
- **Drillpath Geometry & ROW Alignment**
- **Entry/exit angles, pad placement, layout, elevation**
- **Pipe Stress Analysis (installation & operation)**
    - **HDD / DPI**
    - **Pullback / Pipe Support**
    - **Buoyancy Control (HDD)**
- **Annular Pressure Analysis (HDD)**
- **Geotechnical information**

ELEMENTS OF DESIGN

GEOMETRY & ROW/TWS

- ROW & TWS Restrictions
  - 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



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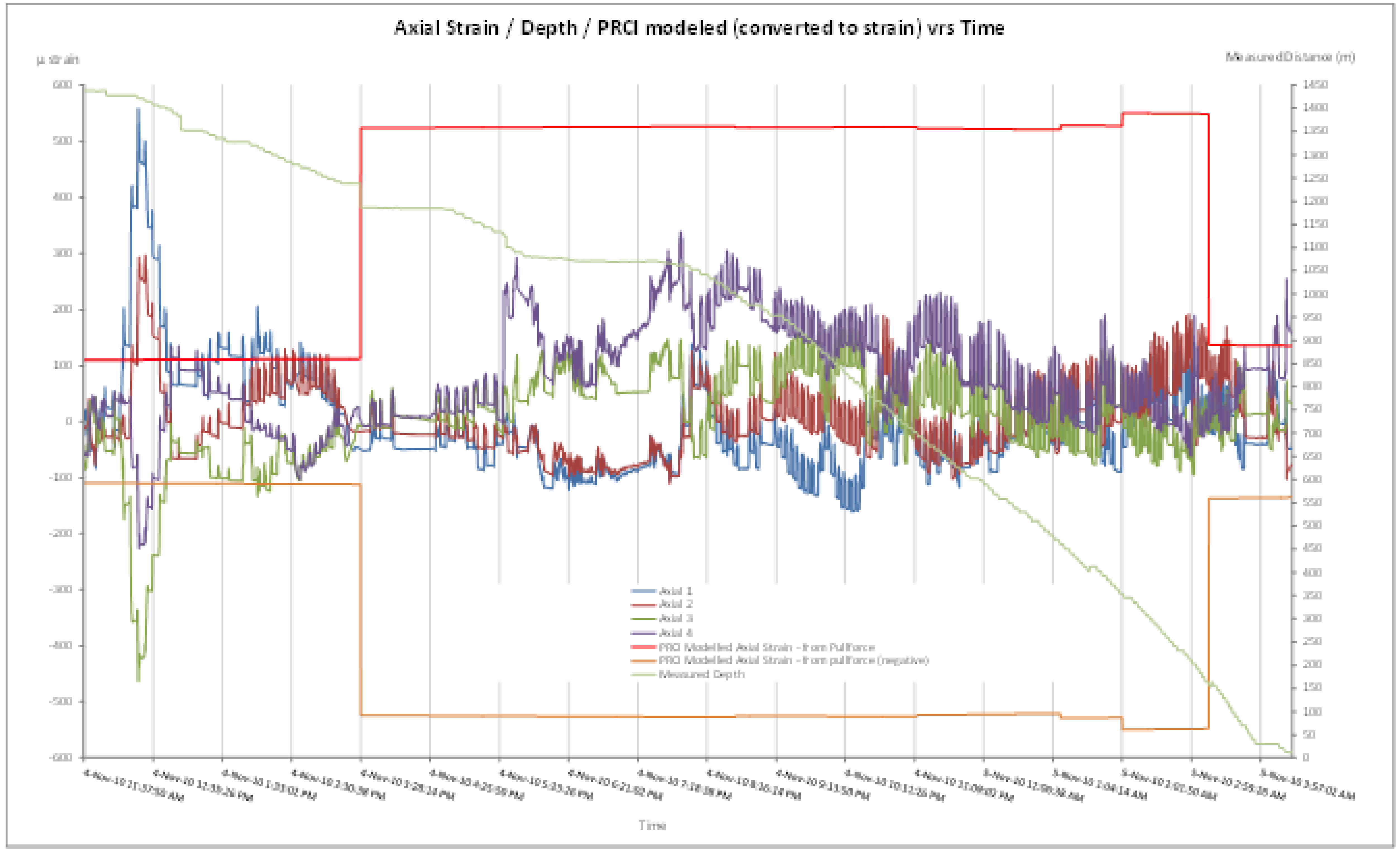
PIPE STRESS ANALYSIS

- 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**



PIPE STRESS ANALYSIS

TENSILE STRESS

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

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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

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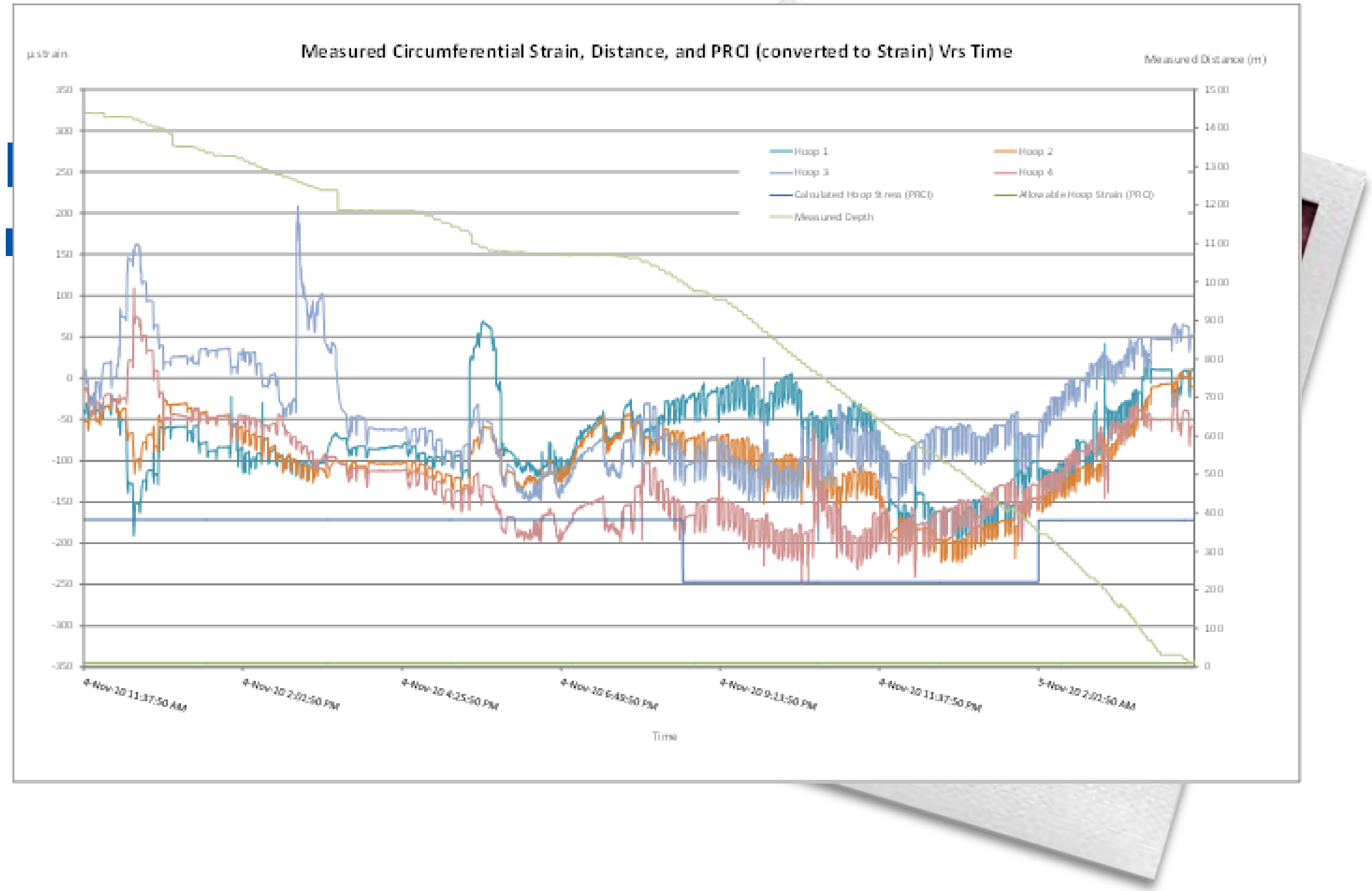

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COMBINED STRESS

- 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

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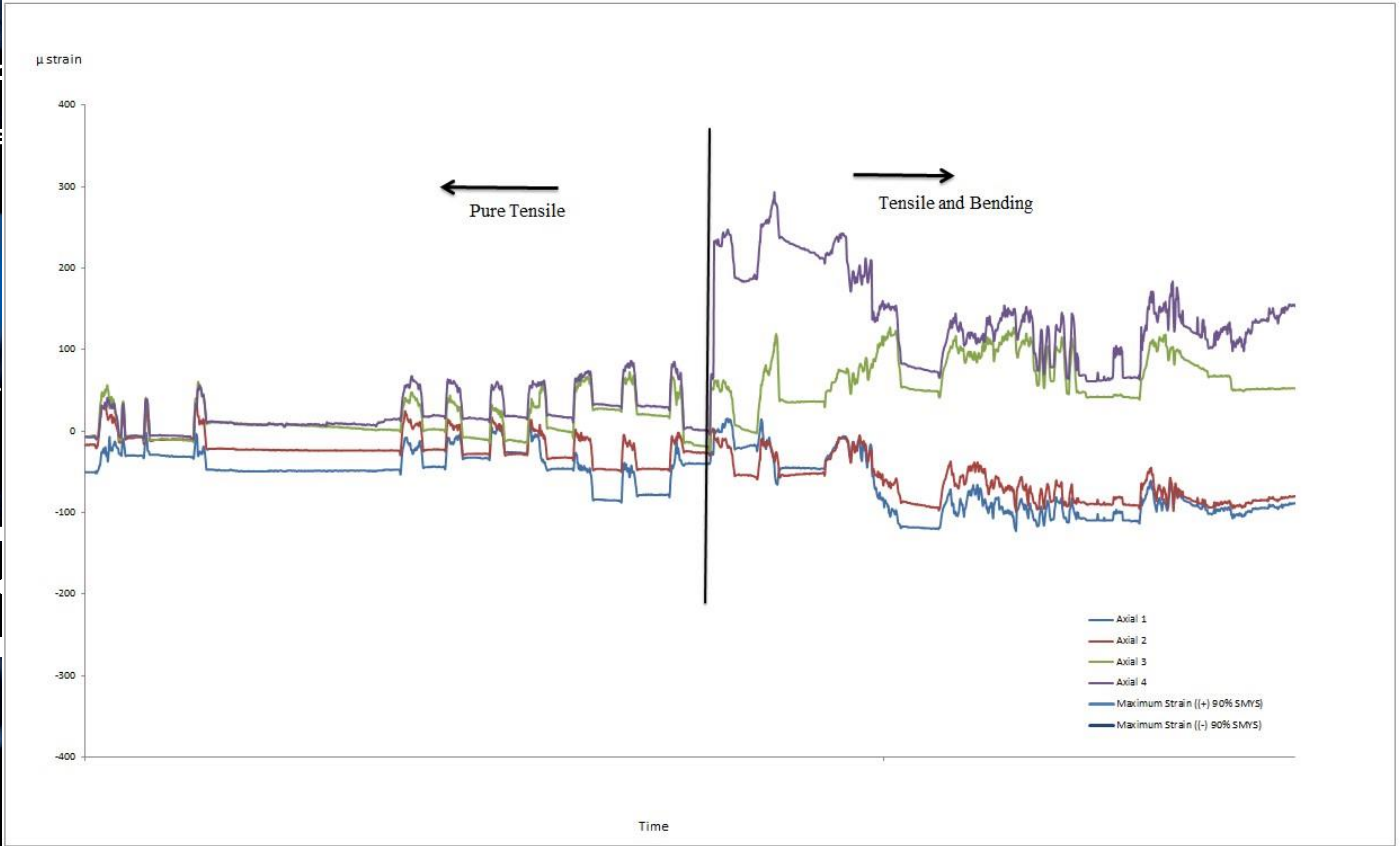

INSTALLATION PULLFORCE

RIG / THRUSTER SIZING

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

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RIG / THRUSTER SIZING

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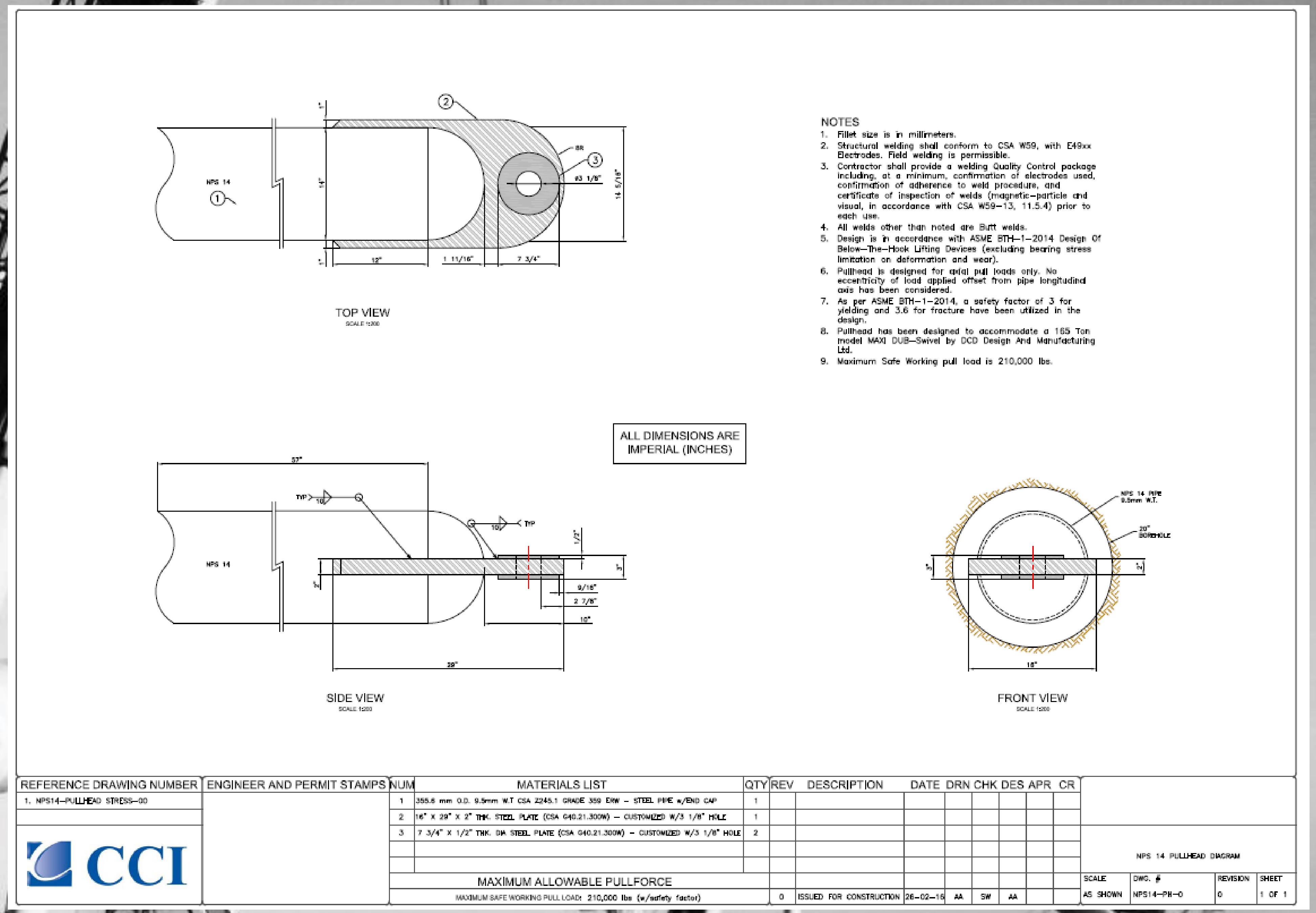
- **Pullback slopes & drill pipe weight**
- **Buoyancy control**

PULL HEAD DESIGN

- **Heads engineered and rated for expected installation loads**



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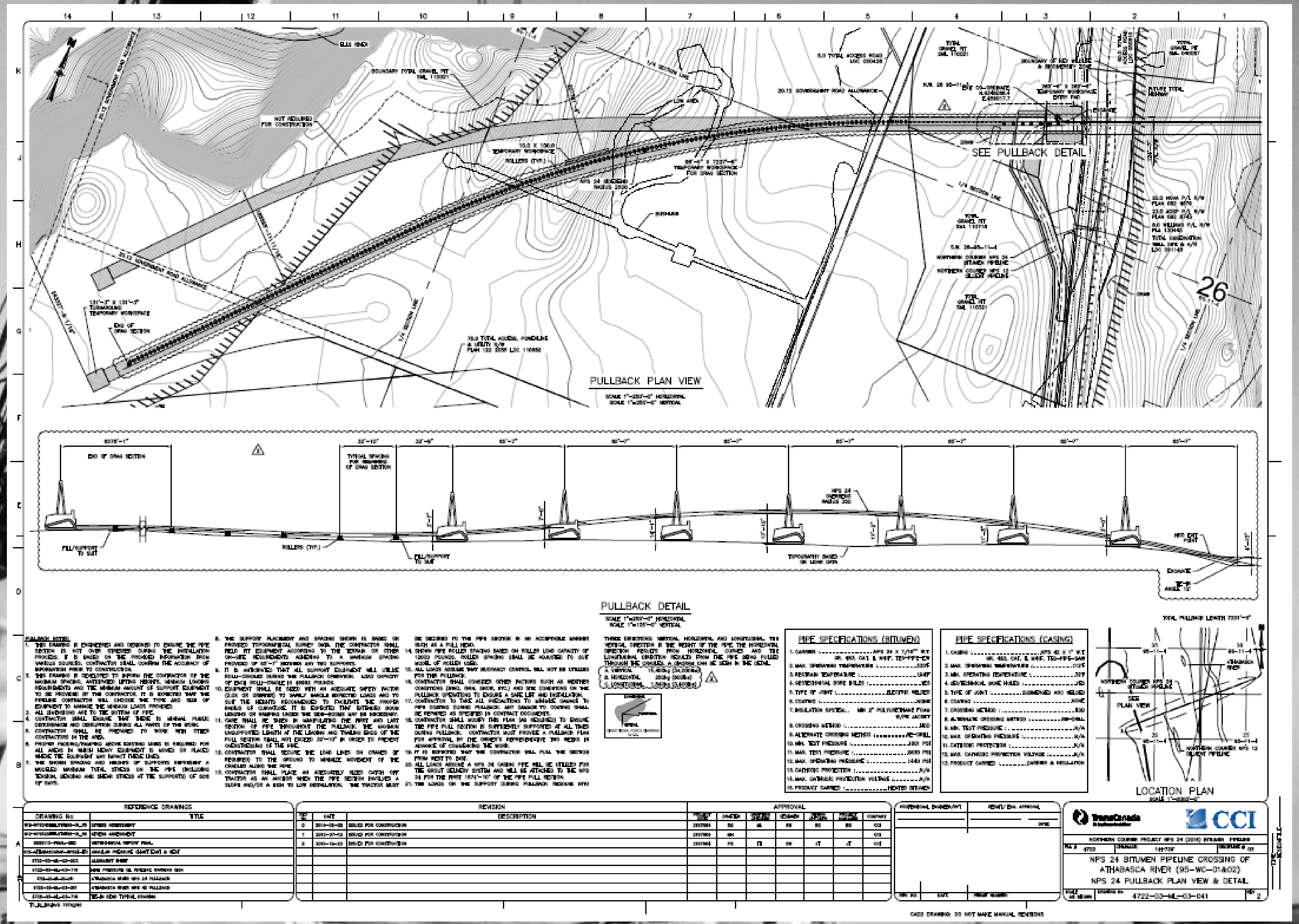
PIPE SUPPORT DESIGN

- Proper equipment spacing & heights
  - Allowable pipe stress
  - Equipment loading capabilities



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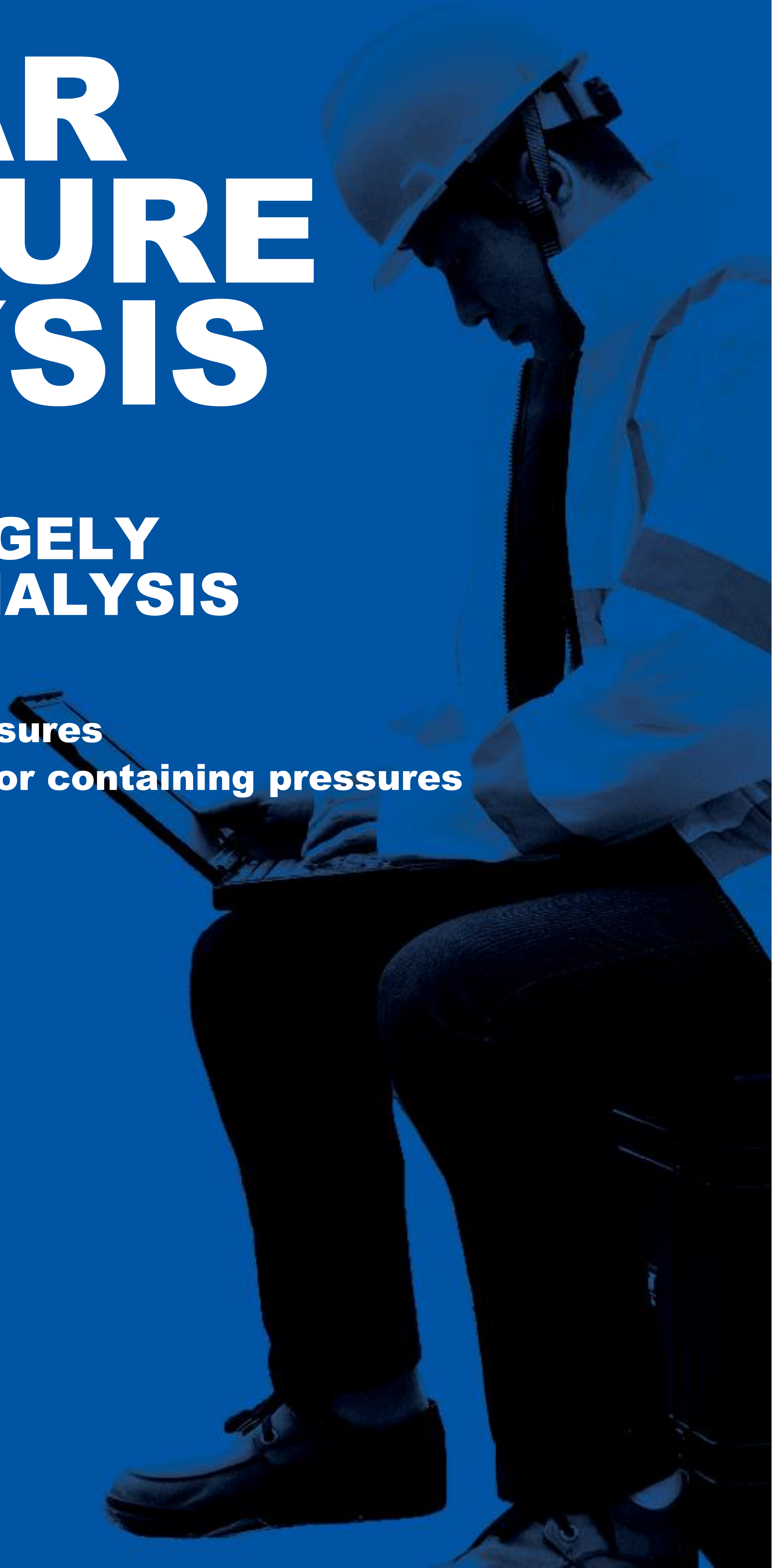
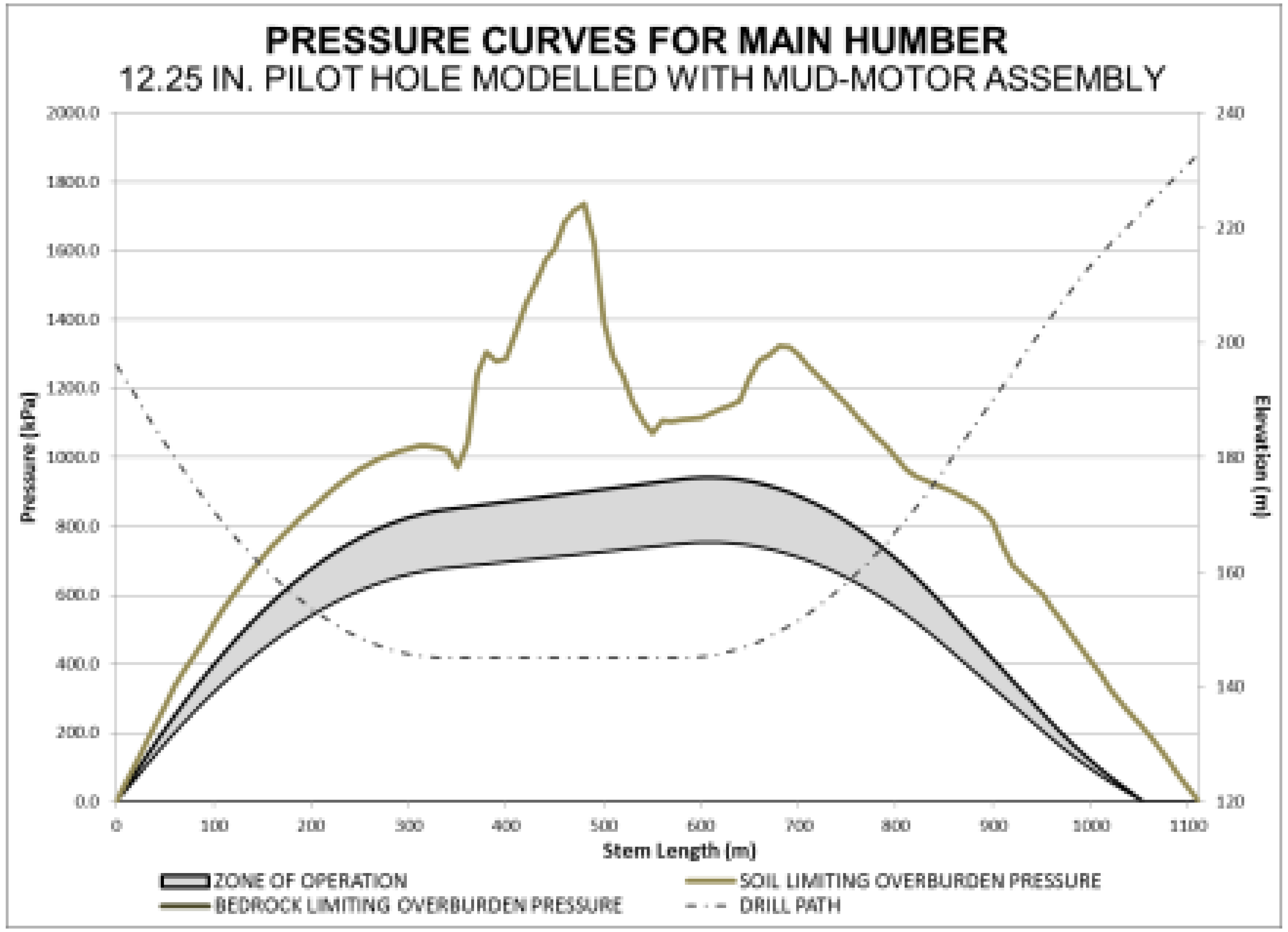
ANULAR PRESSURE ANALYSIS

DRILL PATH LARGELY BASED ON AP ANALYSIS

2 Components:

- **Expected drilling pressures**
- **Expected overburden or containing pressures**





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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**

DRILL

- **BHA si**
- **Drill pi**
- **Fluid p**
- **Drilling methodology**

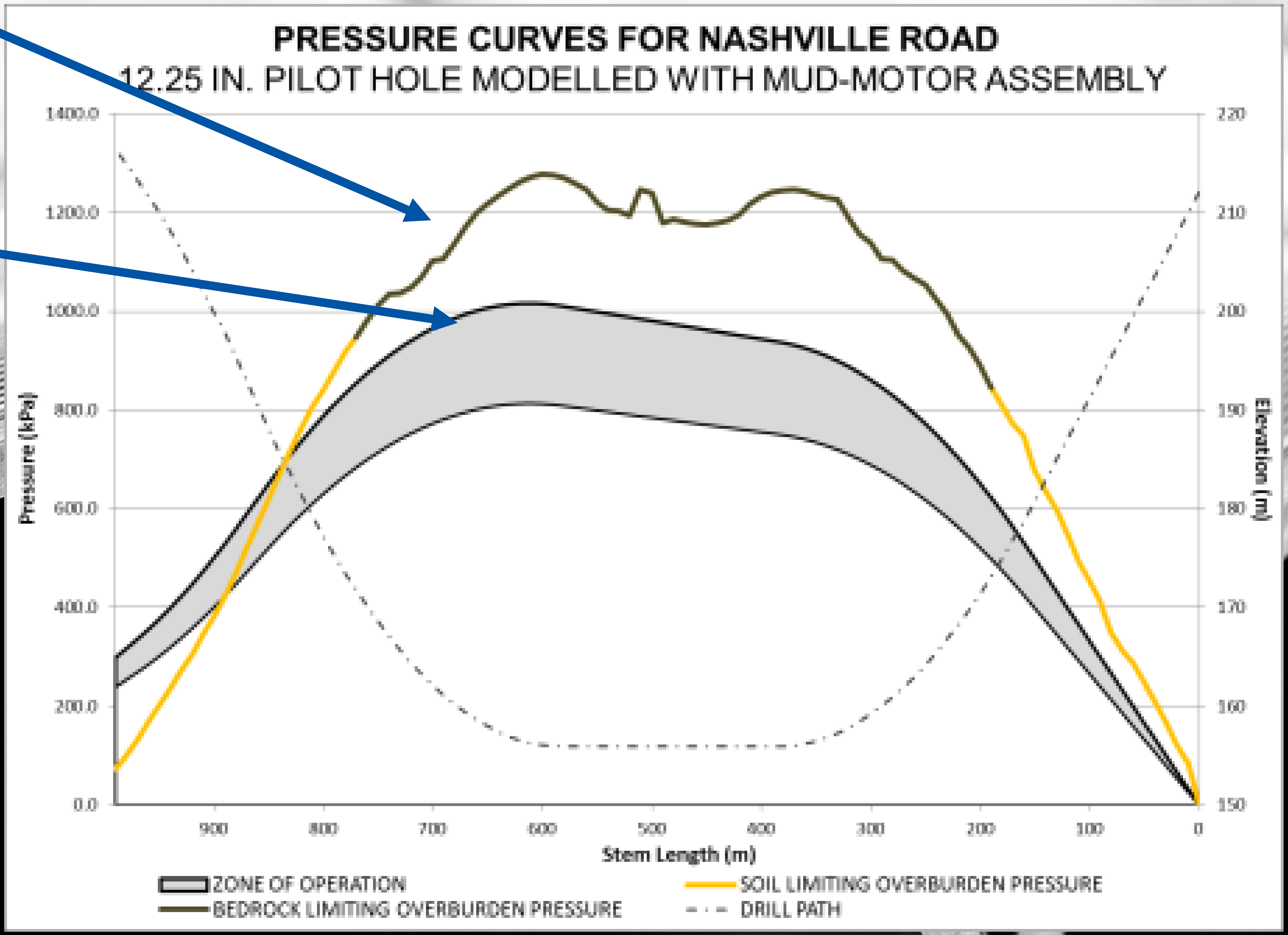
CALCULATING ANNULAR PRESSURE

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



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
  - Significant variances in AP analysis from different sources

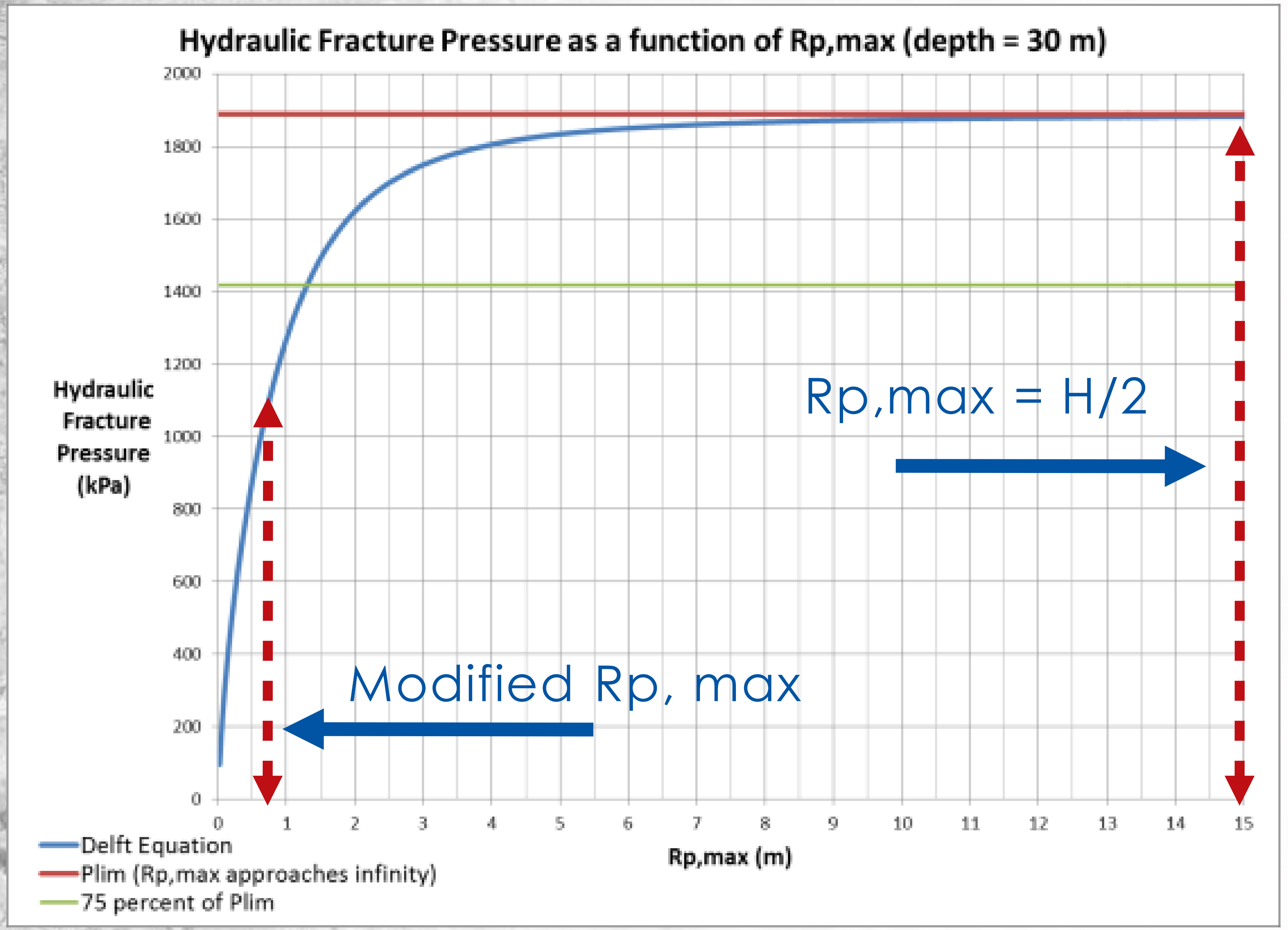
CALCULATING AP CONTAINMENT PRESSURE

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")

$$P'_{max} = [\sigma'_0 \cdot (1 + \sin\varphi) + c \cdot \cos\varphi + c \cdot \cot\varphi] \cdot \left[\left(\frac{R_0}{R_{p,max}}\right)^2 + \frac{(\sigma'_0 \cdot \sin\varphi + c \cdot \cos\varphi)}{G}\right]^{\frac{-\sin\varphi}{(1+\sin\varphi)}} - c \cdot \cot\varphi$$



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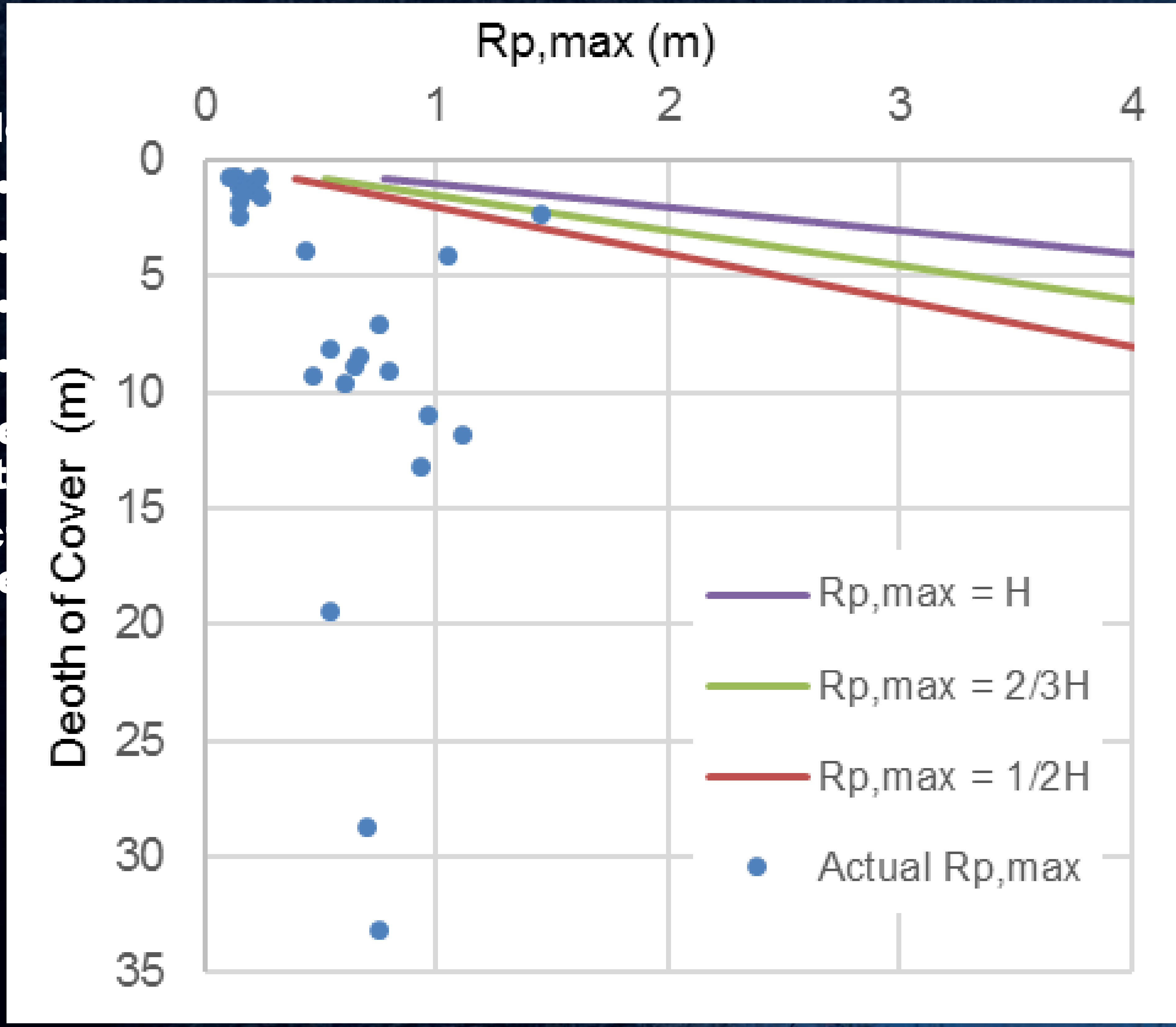

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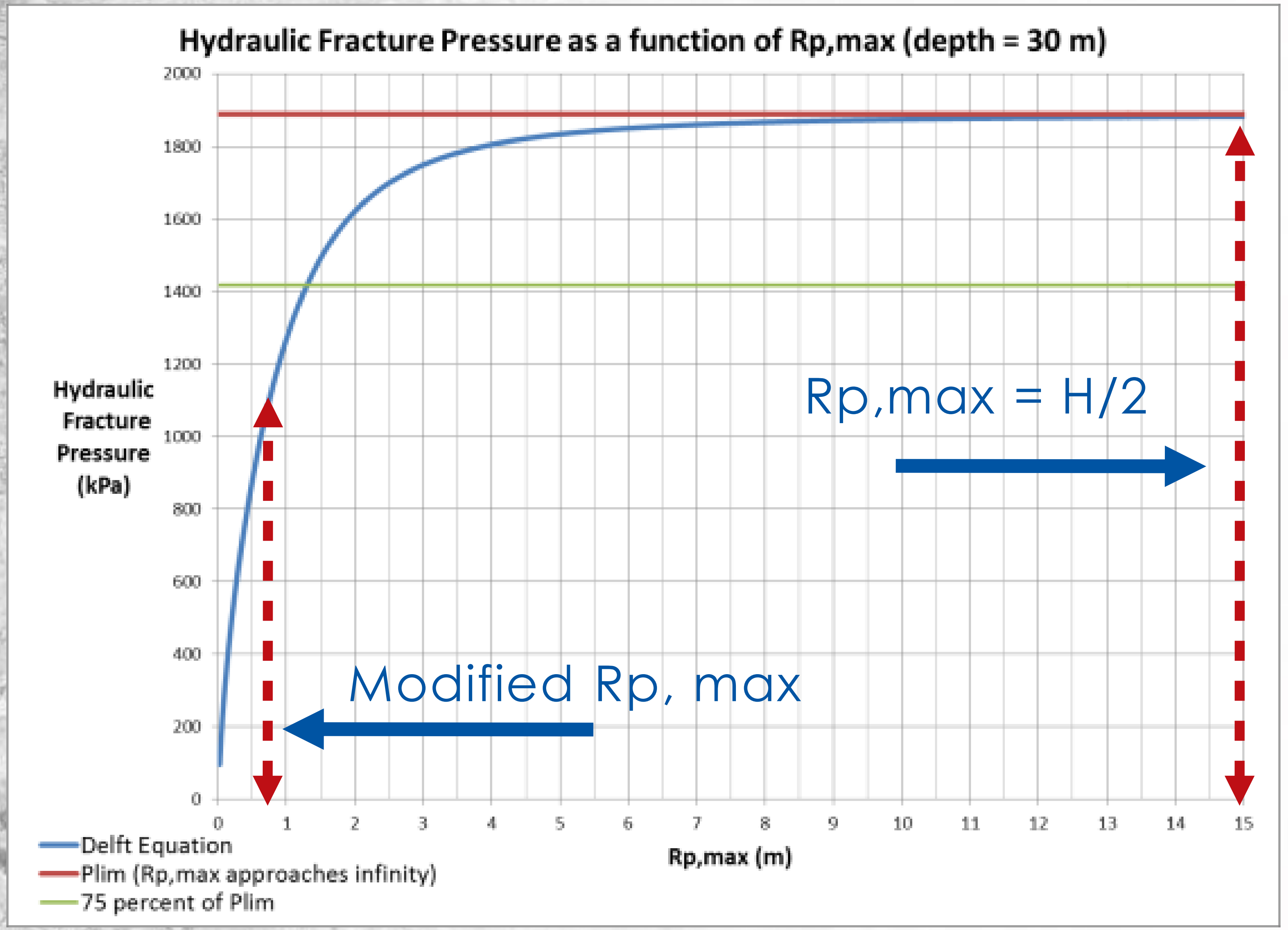
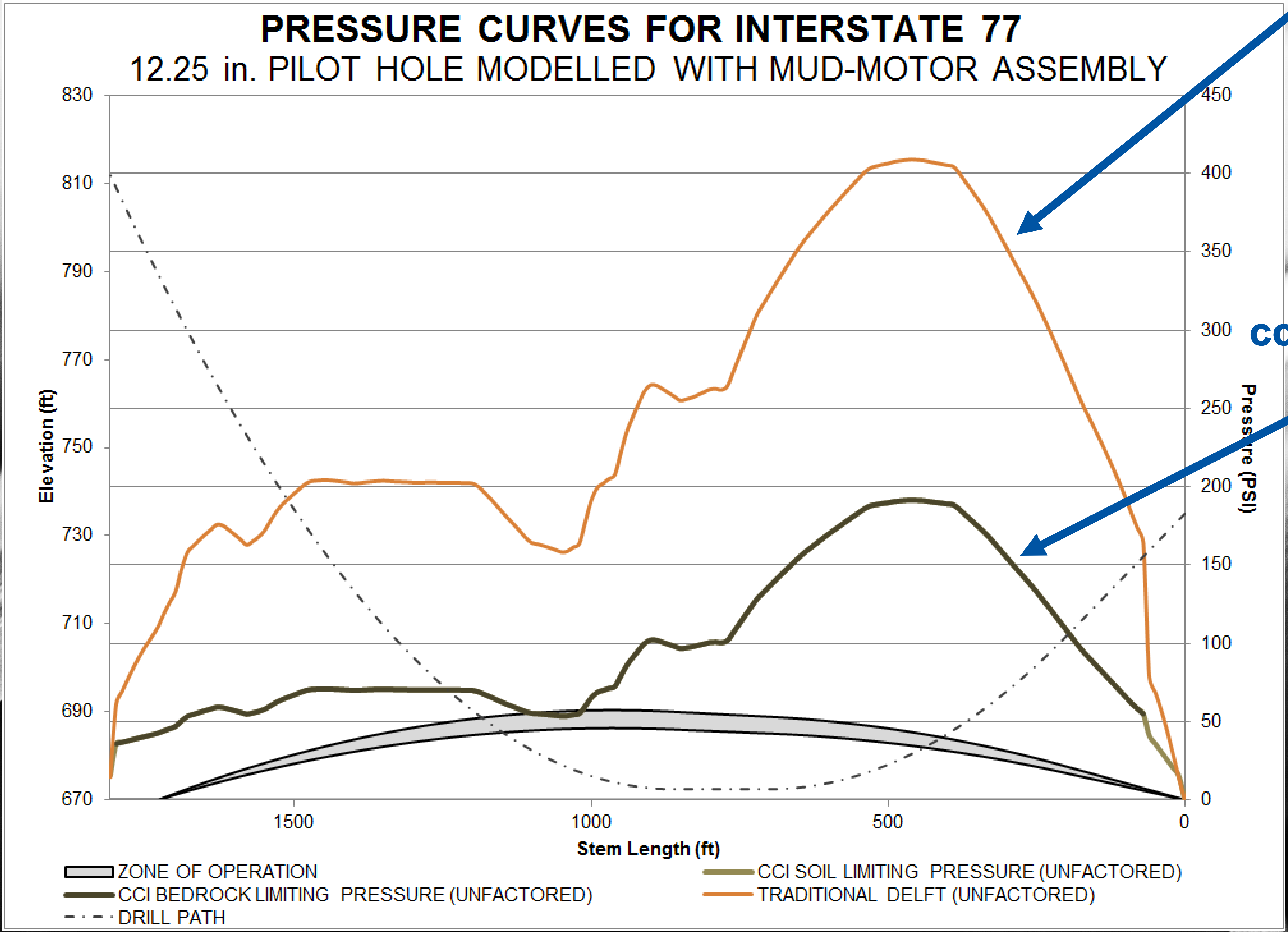


TRADITIONAL DELFT USAGE VS. MOD. DELFT USAGE



Delft Equation using Rp, max as H1/2 (Standard)

Delft Equation using CCI derived Rp,max (CCI)

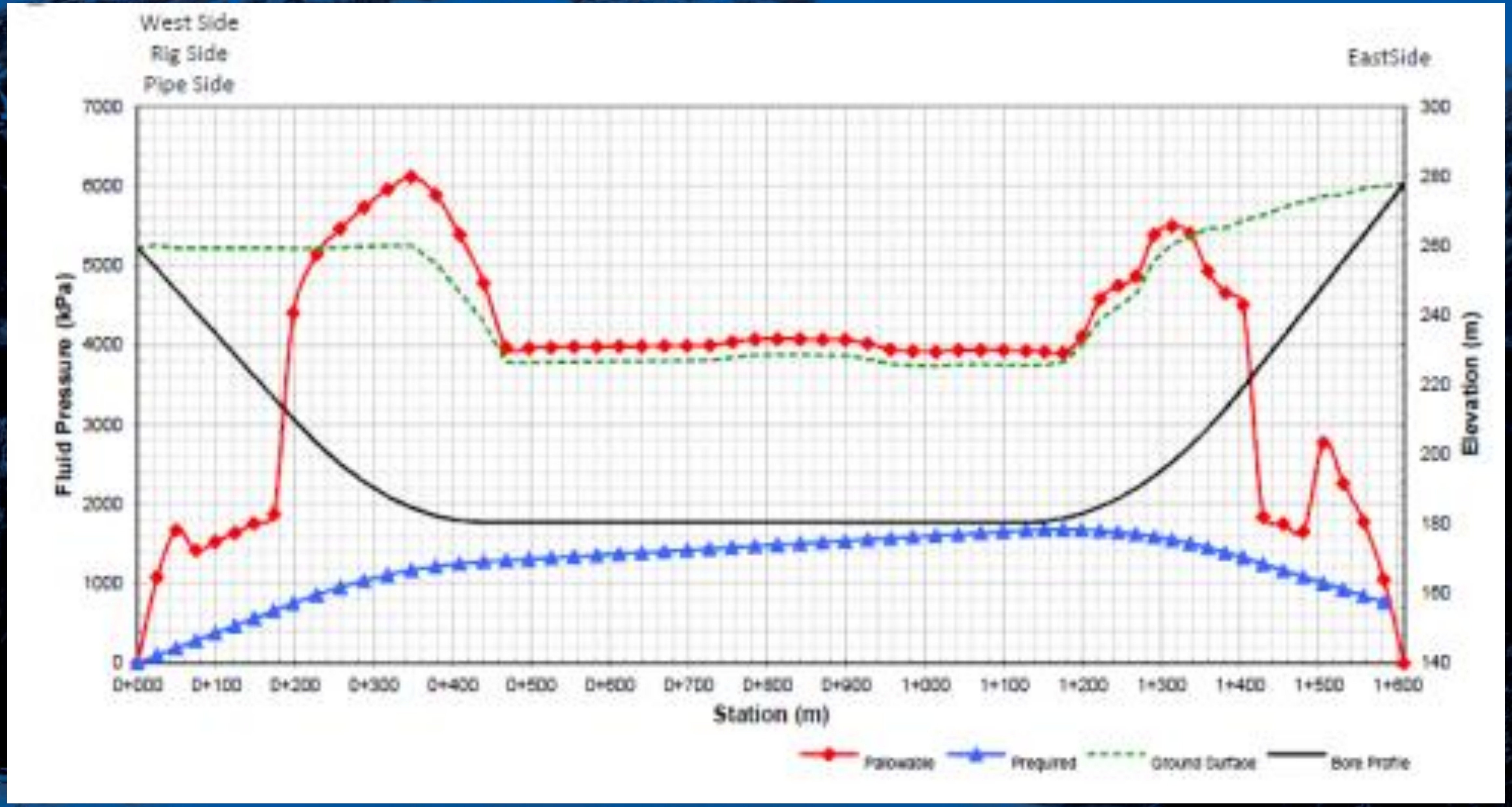
ANULAR PRESSURE ANALYSIS

CASE STUDY

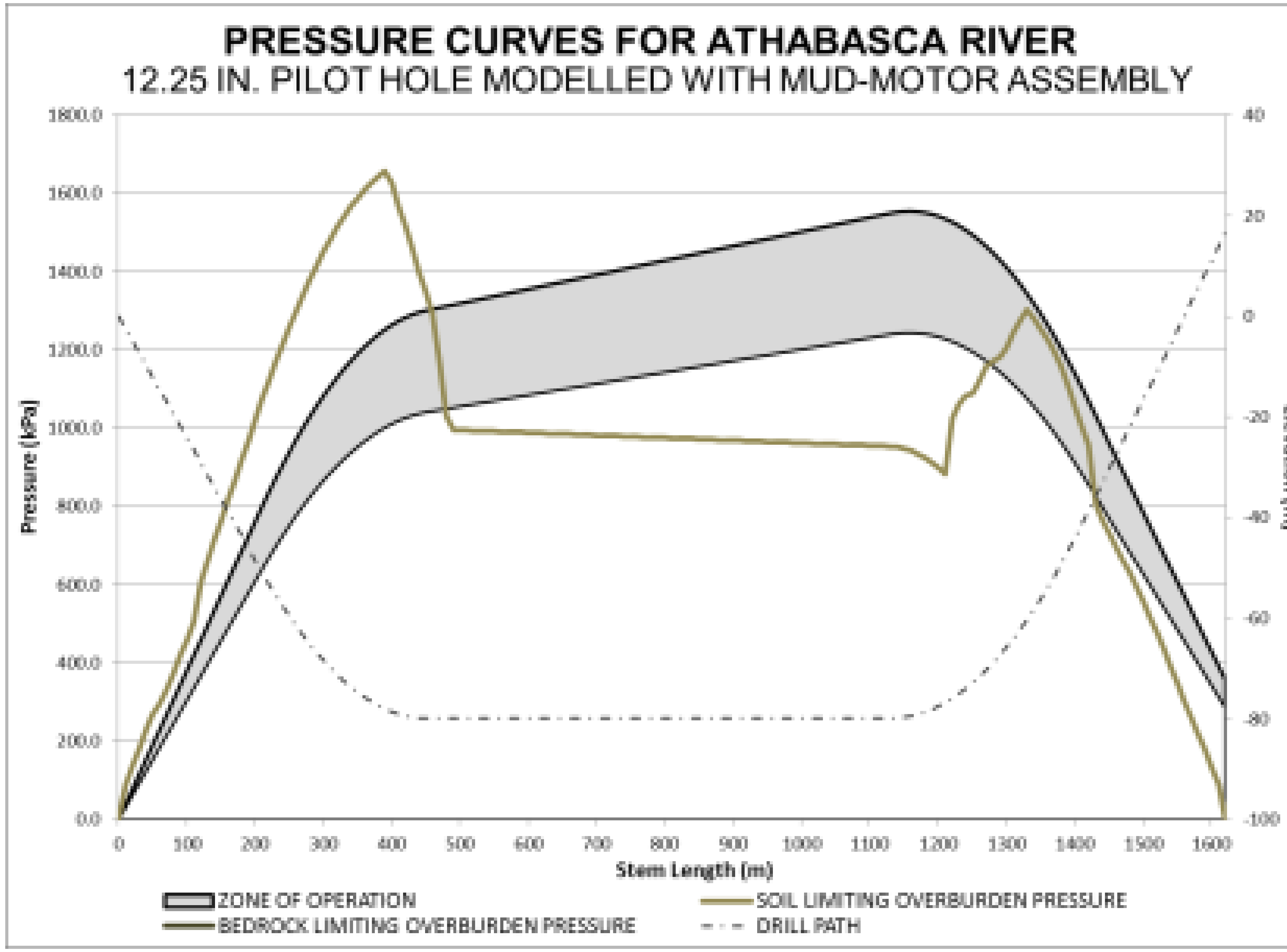
ATHABASCA RIVER

ANULAR PRESSURE ANALYSIS
CASE STUDY
ATHABASCA RIVER

Unmodified Delft AP Chart



Modified Delft AP Chart



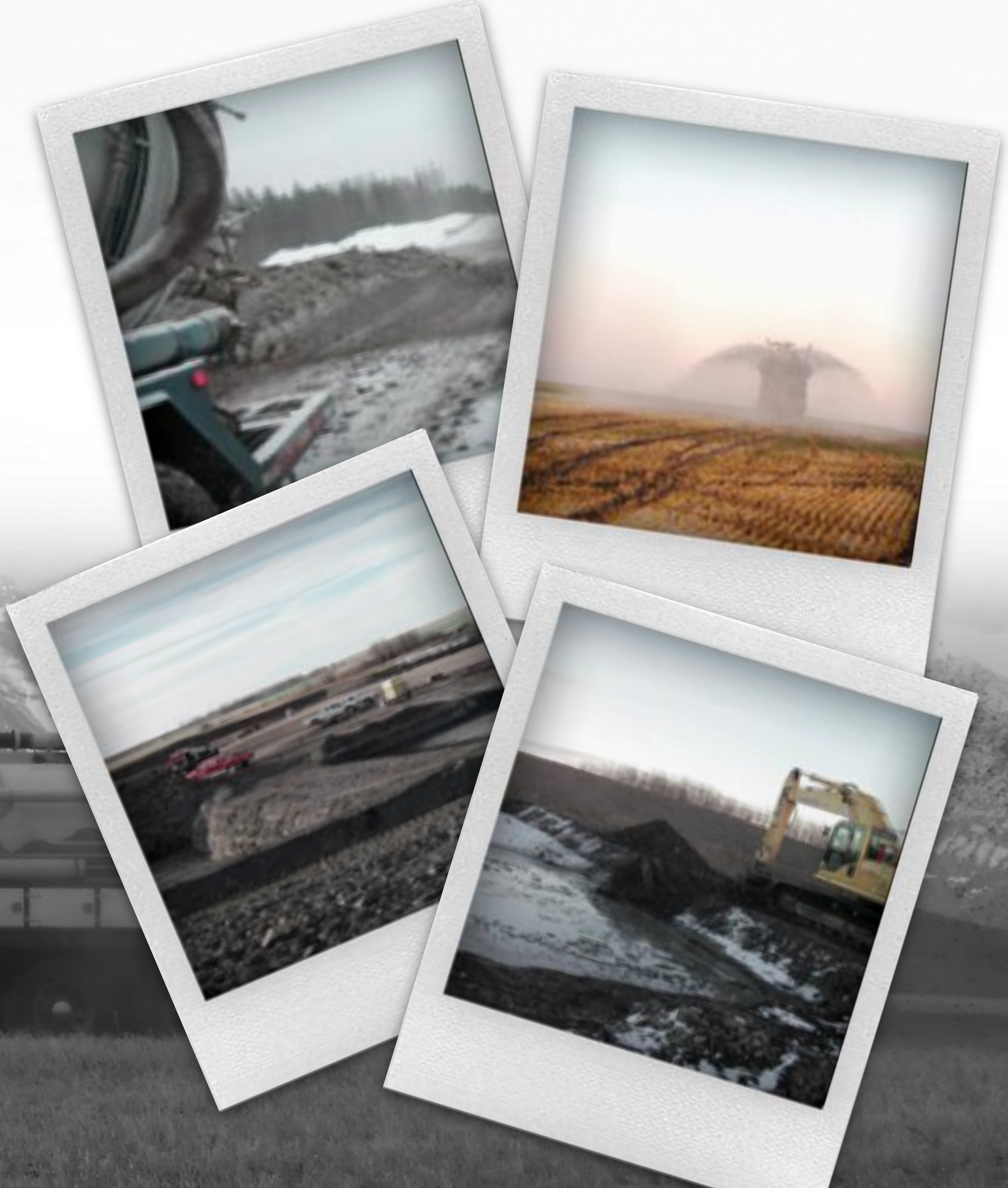
WATER QUALITY MONITORING

- 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



CONSTRUCTION & INSPECTION

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?

CCI

COLLABORATION.
COMMITMENT.
INNOVATION.