37TH INTERNATIONAL NO-DIG FLORENCE 2019

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EXPERIMENTAL STUDY ON PULLBACK LOADS FOR STEEL PIPELINES INSTALLED BY HORIZONTAL DIRECTIONAL DRILLING

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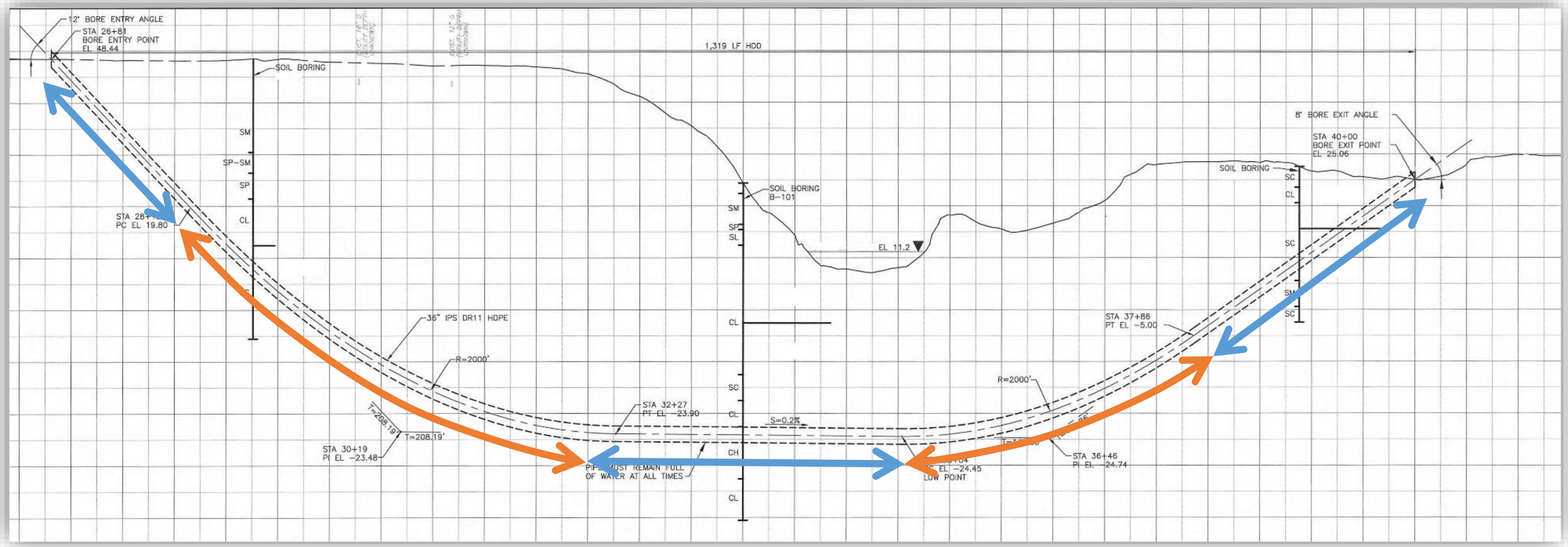
Overview

- **Background**
  - Pullback Load Parameters
- **Database of Completed HDD’s**
  - Theoretical vs. Measured Pullback Forces
- **Strain Monitoring Program**
  - HDD Project Description, Measured Strain Data, & Pull Force Calculation
- **Conclusion**
  - Review of Results and Findings

HDD Design:
Pipeline Research Council International (PRCI)

- PRCI (Installation of Pipeline by Horizontal Directional Drilling-An Engineering Design Guide) currently used in North America as the standard for HDD design.
- Establishes method of calculating HDD installation and operating stresses commonly in use today.
- Divides HDD into sections (tangents and curves) and calculates maximum expected force within each section.



Background:
PULLBACK LOAD PARAMETERS

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- **Above Ground Friction**
  - The friction factor depends on the roughness of the pipe coating surface, ground roughness, types of rollers and lifting devices – 0.1 – 0.8 (Chehab, 2008)
  - Netherlands Standardization Organization (NEN 3650, 2007) - 0.3 (pipe – ground) and 0.1 (pipe – roller)
  - Roller-Pipe friction coefficient of 0.1

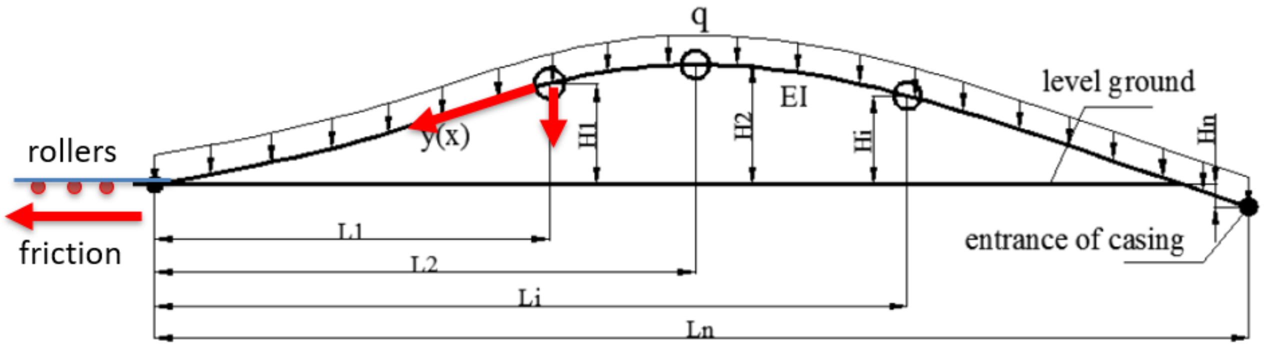
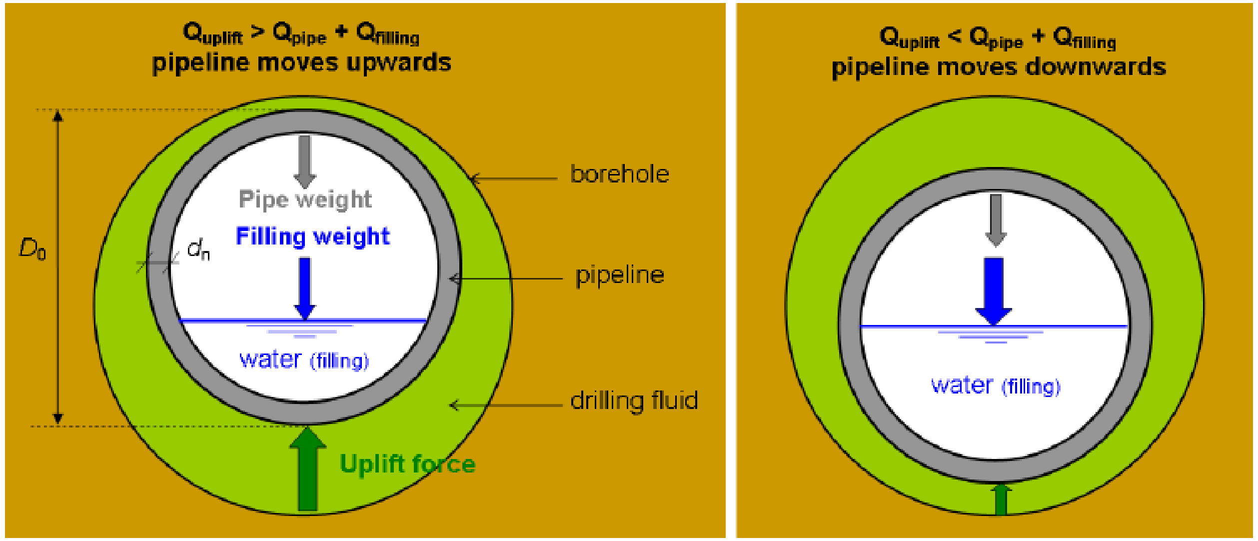


Diagram of forces during pipe lifting

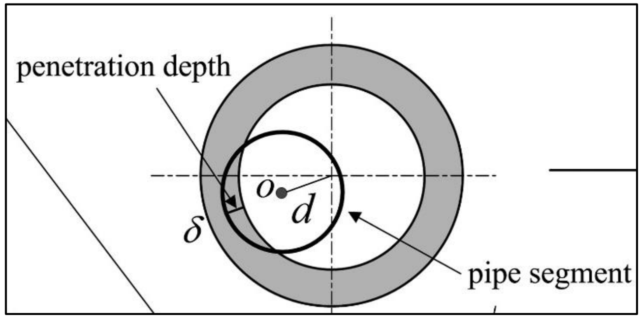
Background:
PULLBACK LOAD PARAMETERS

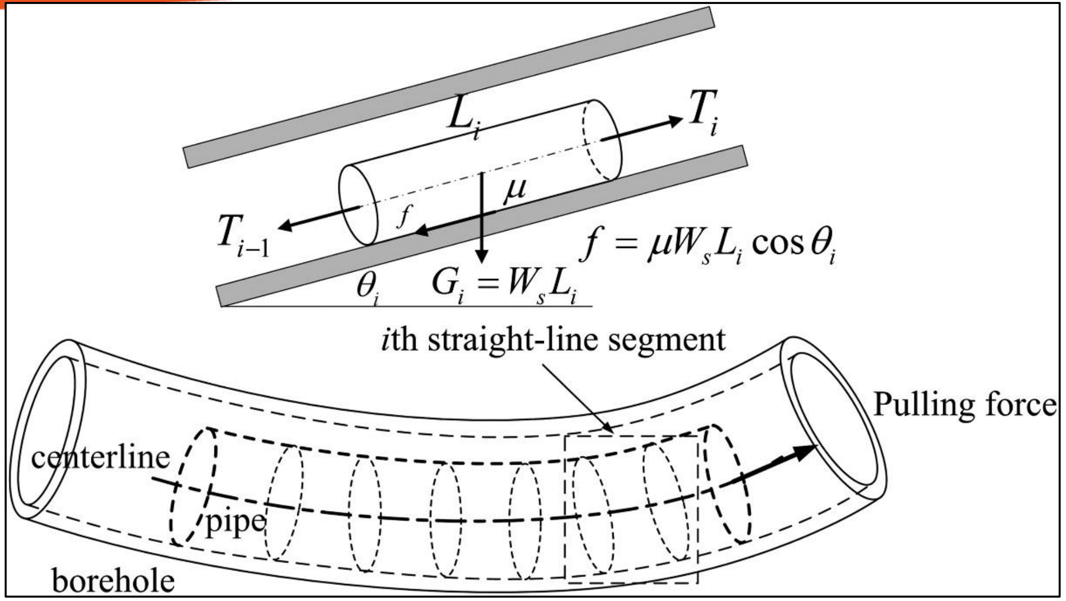
- **Submerged Weight**
  - Typical mud density: 1060 to 1320 kg/m3
  - Upper slurry density 1500 kg/m3 – ASTM F1962
  - Upper limit 1440 kg/m3 – PRCI

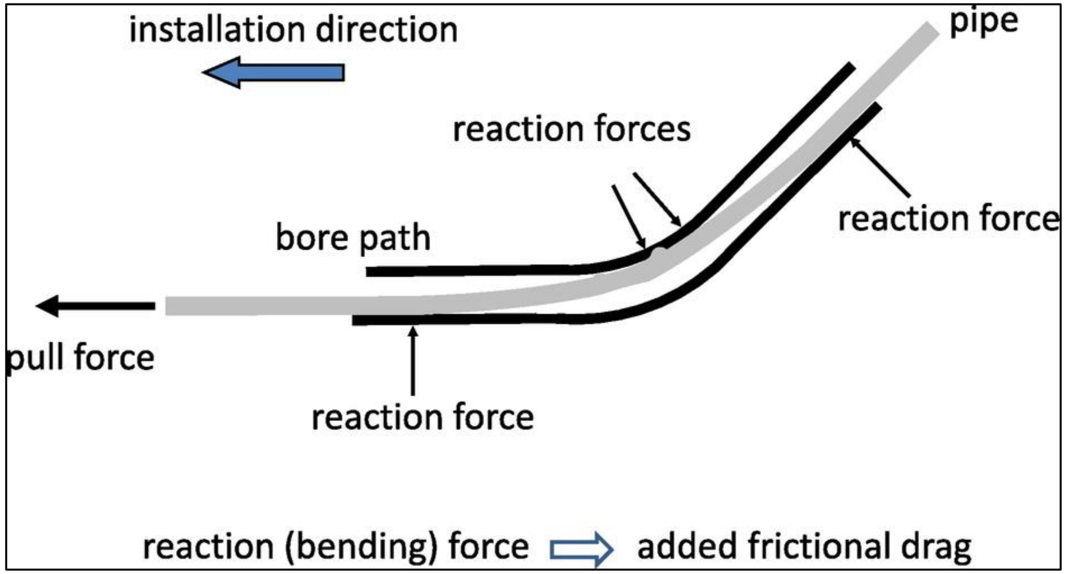


Schematic of submerged weight and buoyancy control

Background:
PULLBACK LOAD PARAMETERS

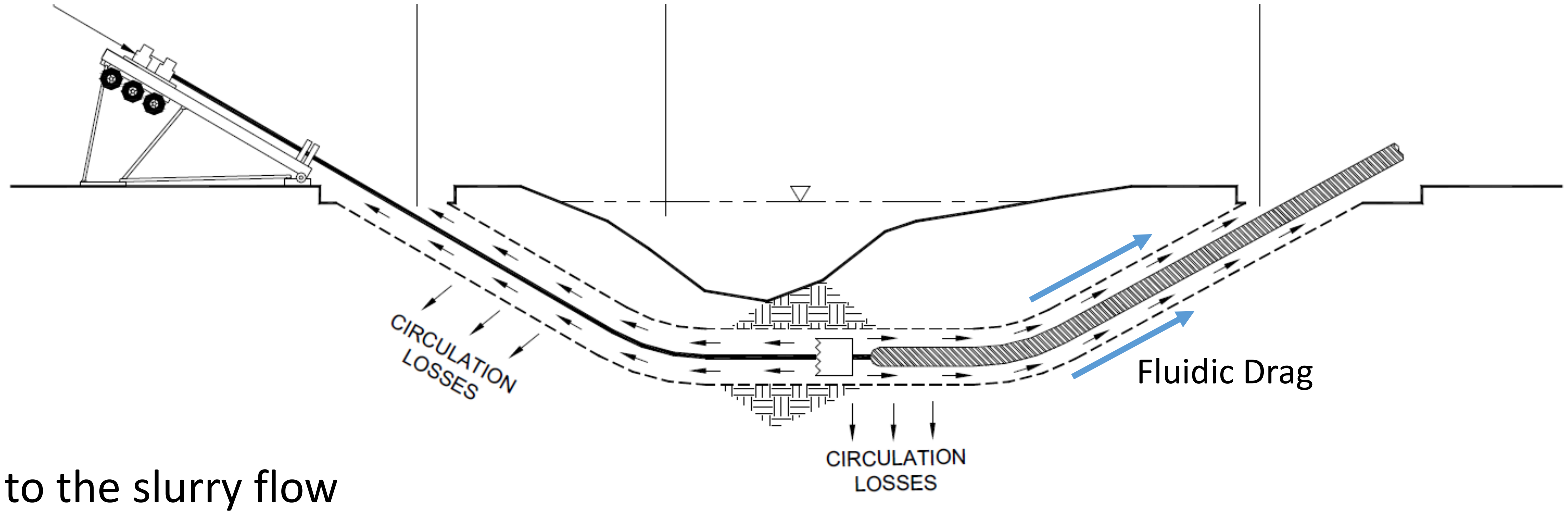




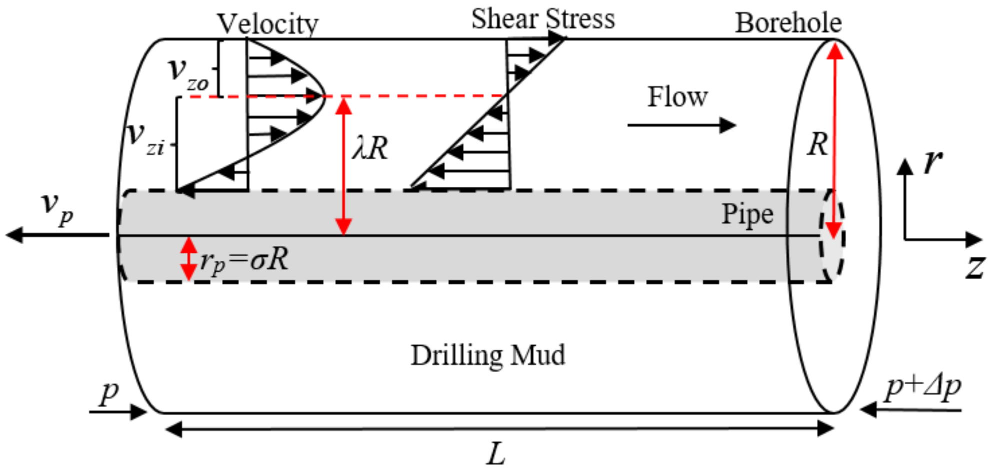


- **Borehole Friction**
  - Straight Section
  - Curved Sections – Additional contact force due to pipe stiffness, capstan effect, radial soil displacement
  - Friction coefficient depends on
    - pipe-soil or pipe-bedrock interface in different materials
    - presence of mud filter cake
    - importance of mud age on the interface
    - the magnitude of the applied normal force

Background:
PULLBACK LOAD PARAMETERS



- **Fluidic Drag**
  - Resistance to the pipe movement due to the slurry flow
  - Different mud friction values
    - 345 (0.05 psi) - originally in PRCI and NEN
    - 172 Pa (0.025 psi) - PRCI
    - 50 Pa - NEN 3650



Database of Completed HDD's
THEORETICAL VERSUS MEASURED PULLBACK FORCES

- Two hundred (200) commercial HDD projects completed throughout Canada
- Designed, inspected or monitored during their construction by CCI Inc. between 2012 to 2018
- Pipes ranging in diameter from 88.9 mm (NPS 3) to 1066.8 mm (NPS 42)
- HDD rigs utilized ranged in size from 80,000 lbs (push/pull) to 1,100,000 lbs
- Crossing lengths varied from 100 m to 2,000 m
- The recorded rig pull loads were compared with the estimated pull forces for each project

THEORETICAL VERSUS MEASURED PULLBACK FORCES

- The theoretical pull forces estimates were based on PRCI model.

drill strings friction	Yes
above ground friction	Yes
pipe-borehole friction	0.3
pipe-roller friction	0.1
slurry density	1438 kg/m3
fluidic drag coefficient	172 Pa
additional safety factors	No

- Error (%) = (Theory – Actual)/Actual x 100
- A negative error means the theoretical calculation is less than the actual measurements
- A positive error represents the amount of overestimation

THEORITICAL VS. ACTUAL PULL FORCES BASED ON HDD SIZE

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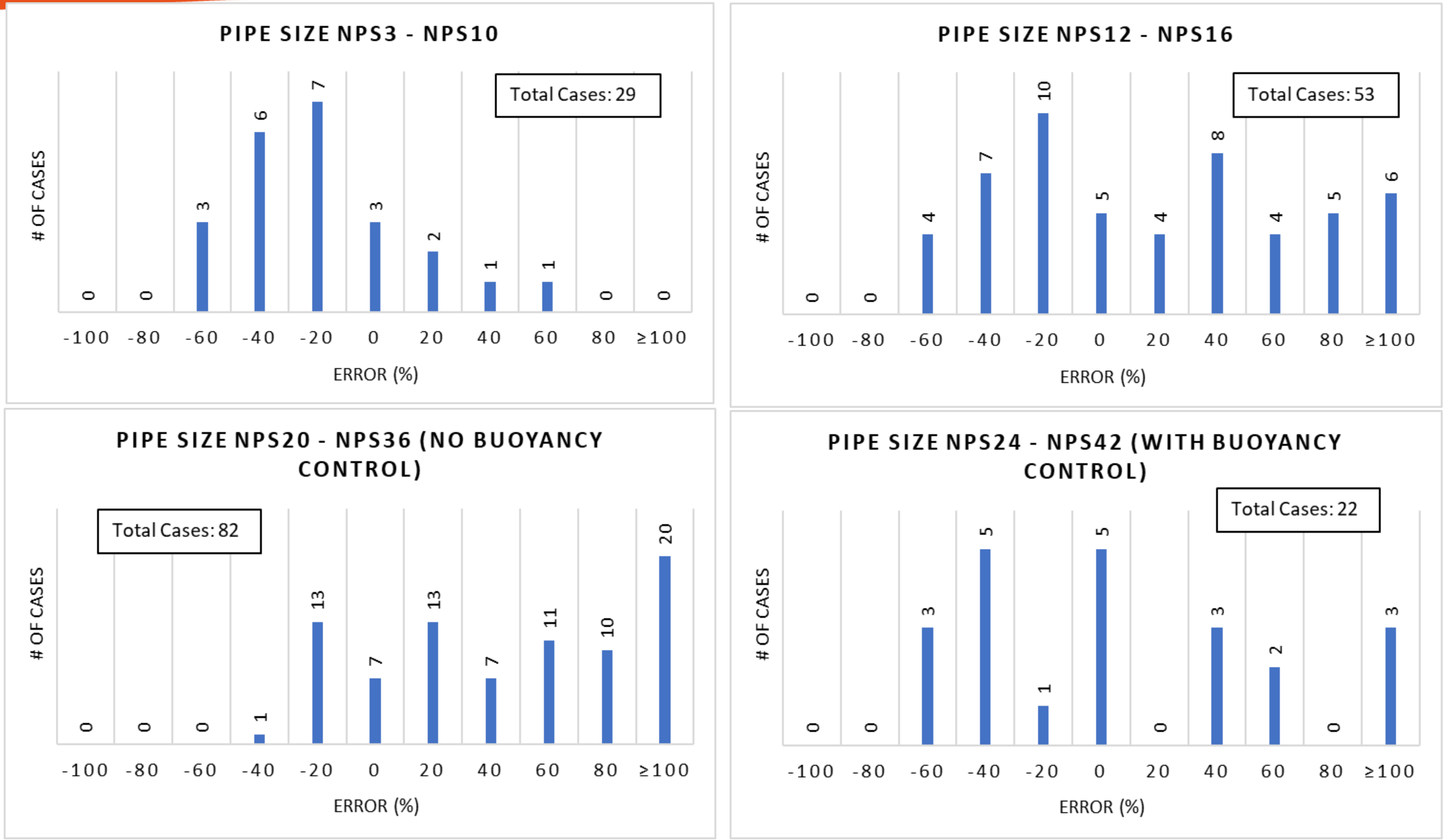
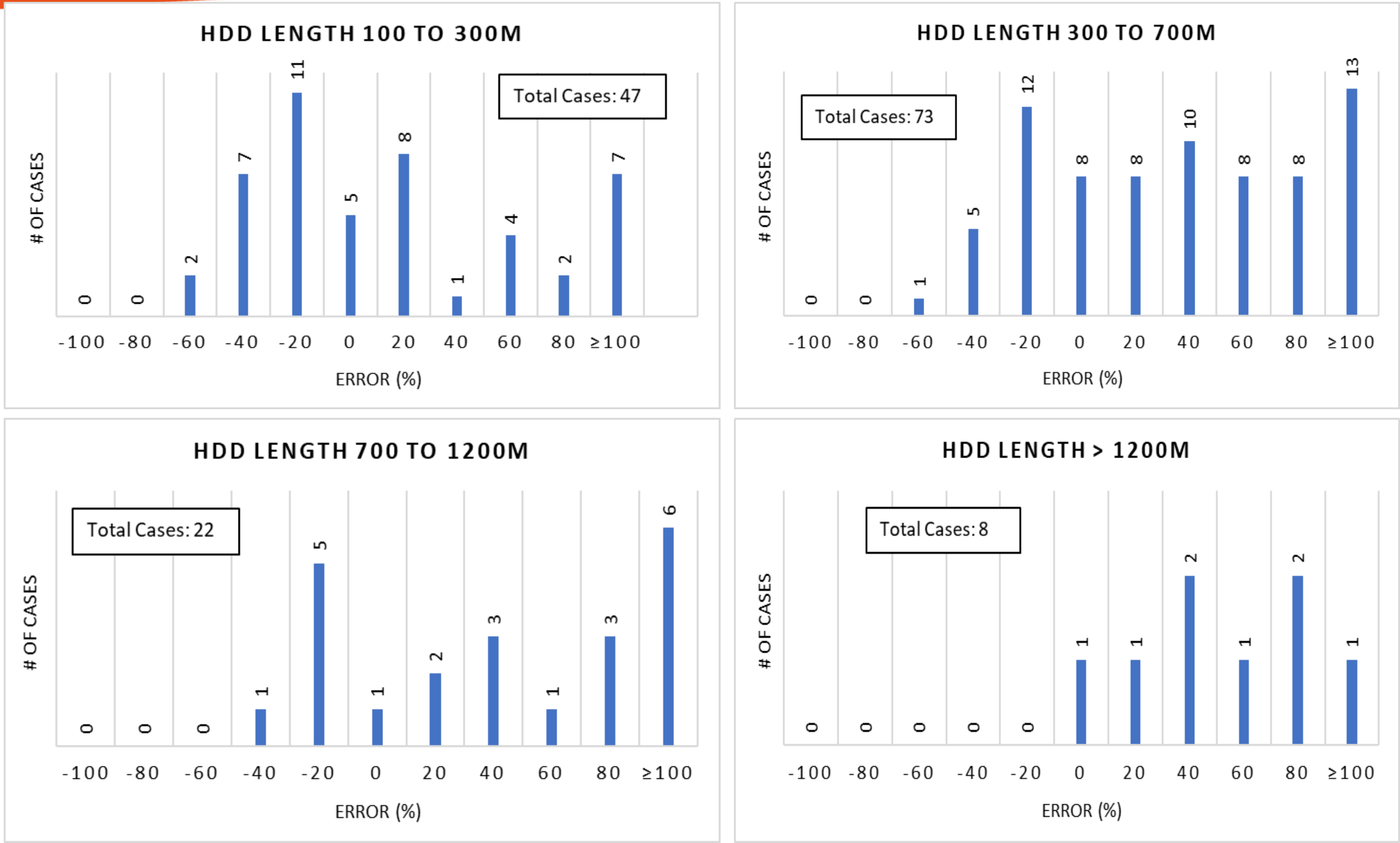
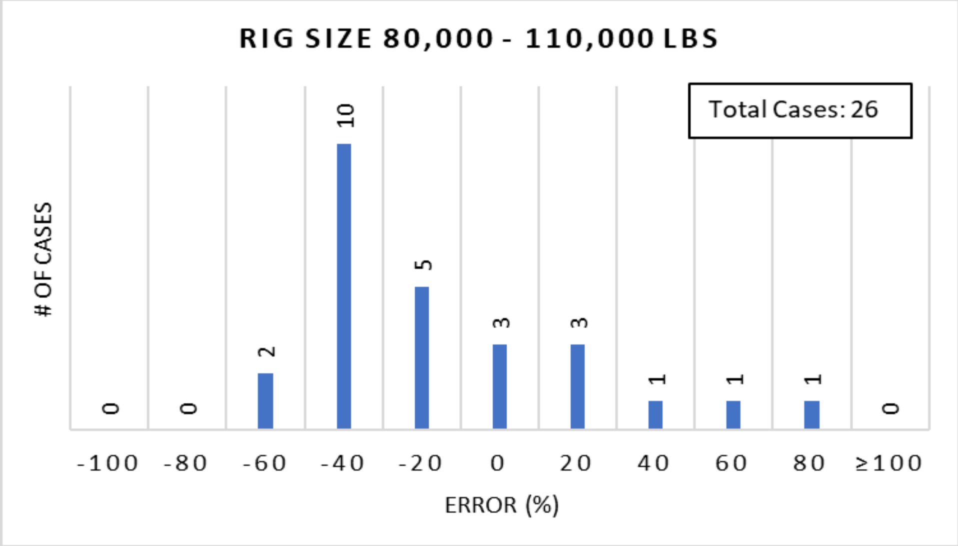
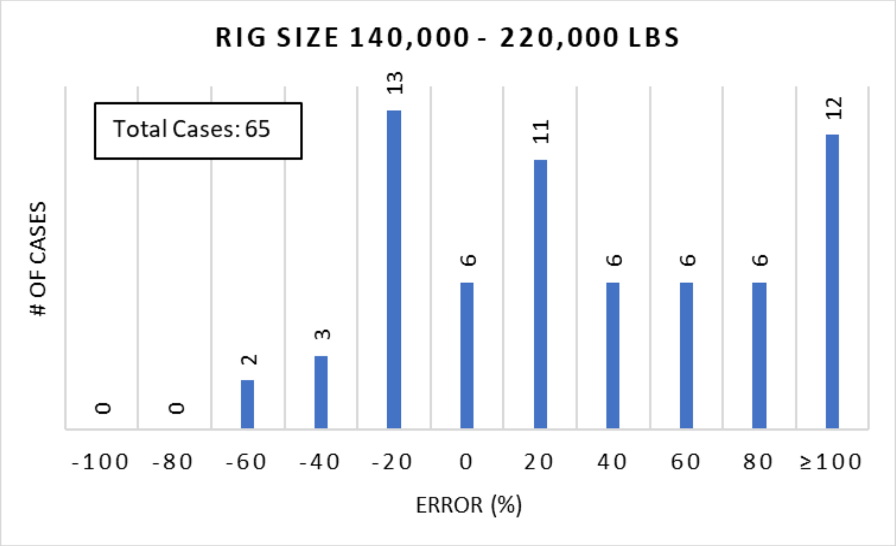


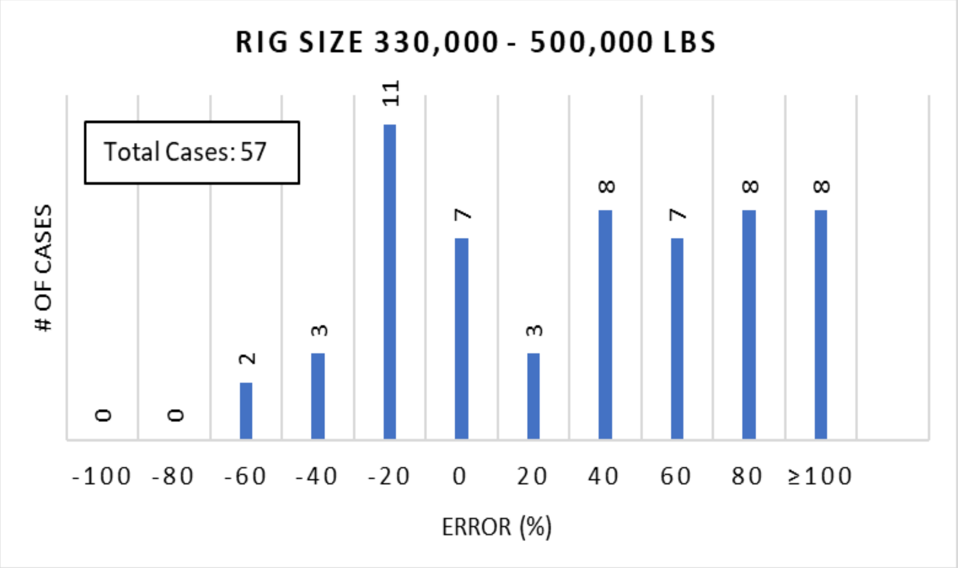
THEORITICAL VS. ACTUAL PULL FORCES BASED ON HDD LENGTH

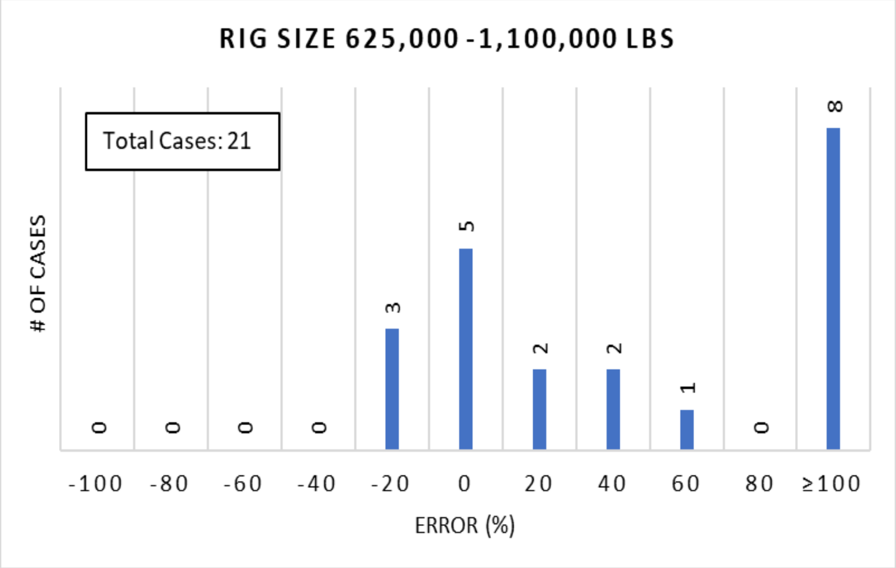


THEORITICAL VS. ACTUAL PULL FORCES BASED ON HDD RIG SIZE



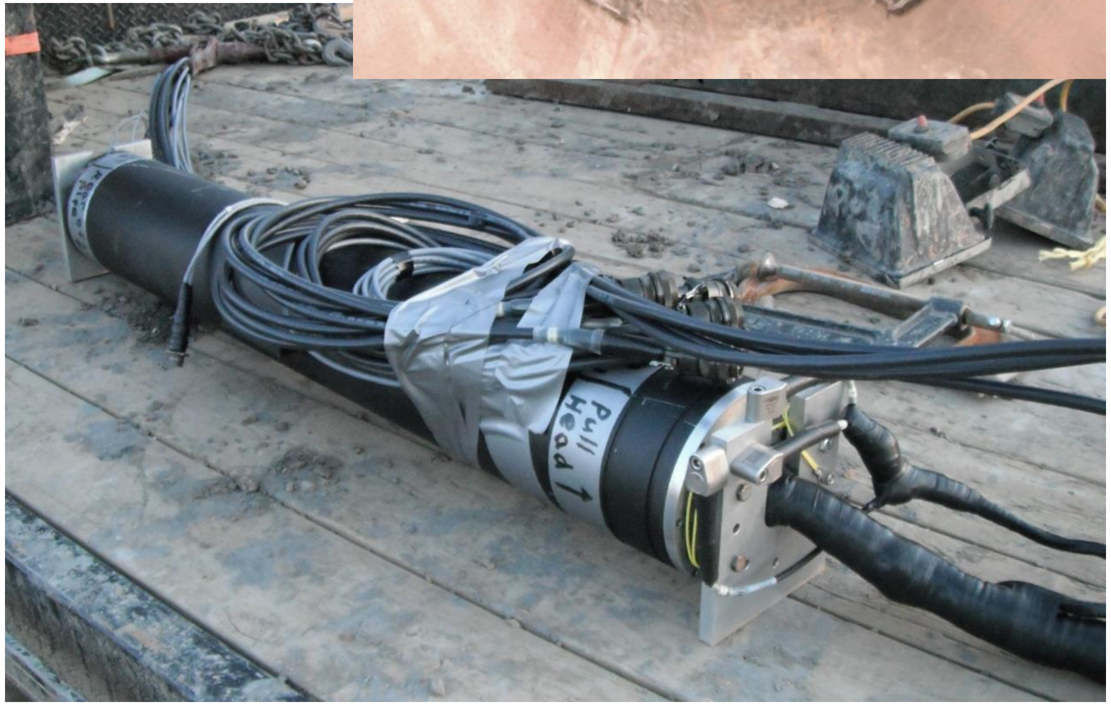






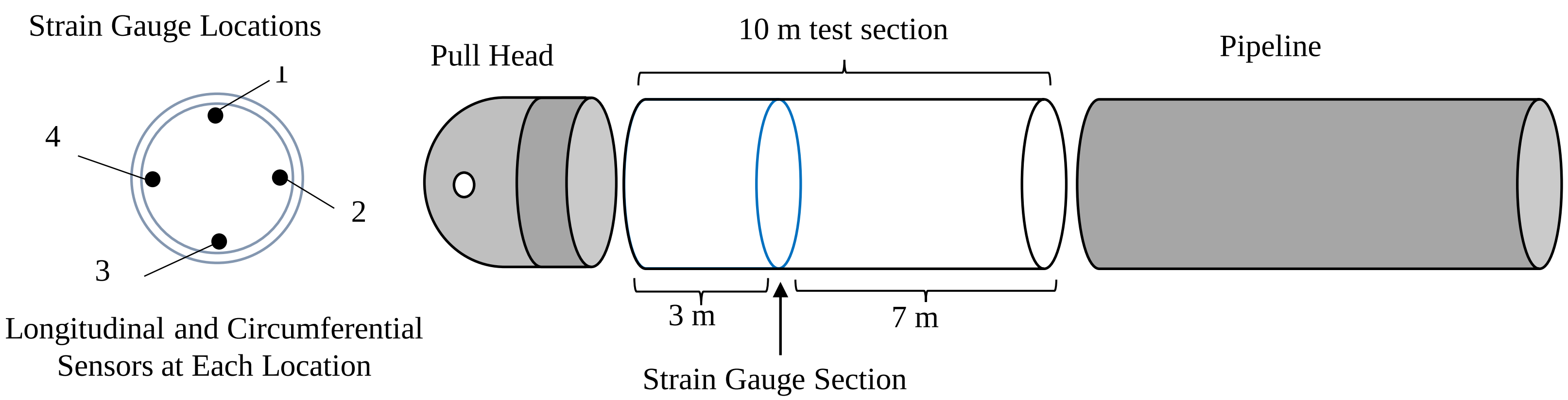
STRAIN MEASUREMENT TOOL

- Utilizes multiple (8-16) strain gauges on interior pipe wall
- Strain measurements feed into central tool housing mounted inside the pipeline
- Water-tight, for use in installations incorporating fill-water for buoyancy control
- Battery powered
- Developed for NPS 8 pipe and larger



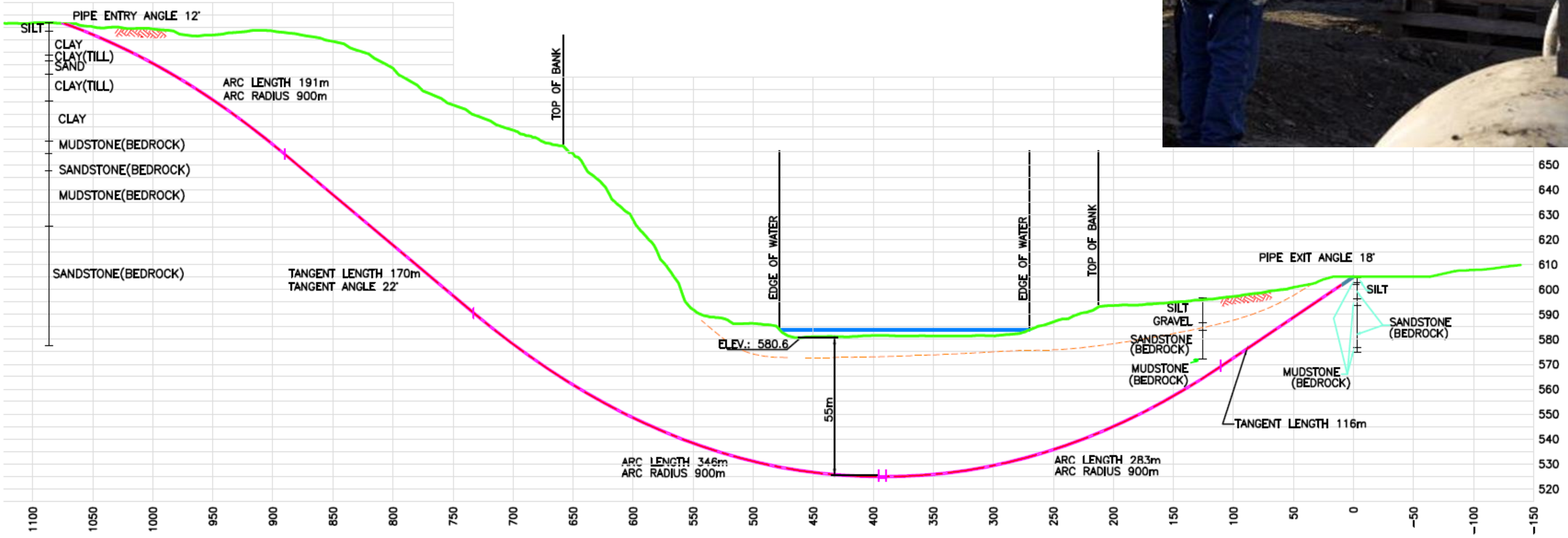
STRAIN MEASUREMENT TOOL

- Each gauge location includes 1 Axial + 1 Circumferential strain gauge
- Installed prior to pullback, near the pull head
- Full testing & calibration conducted in shop setting prior to application in field

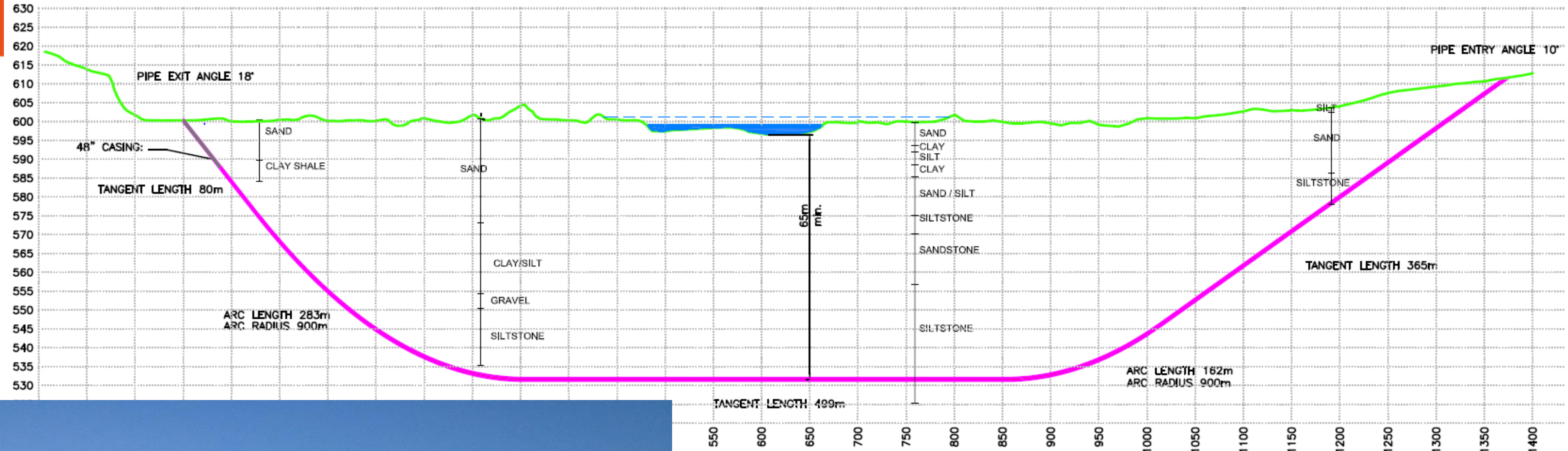


FIELD MEASUREMTNS

- **HDD 1** included a river crossing of 1,112 m long, AB, Canada
- NPS 30 steel pipeline



FIELD MEASUREMTNS



- **HDD 2** was a 1,390 m installation across an 800 m wide valley, AB, Canada
- NPS 30 steel pipeline

FIELD MEASUREMTNS

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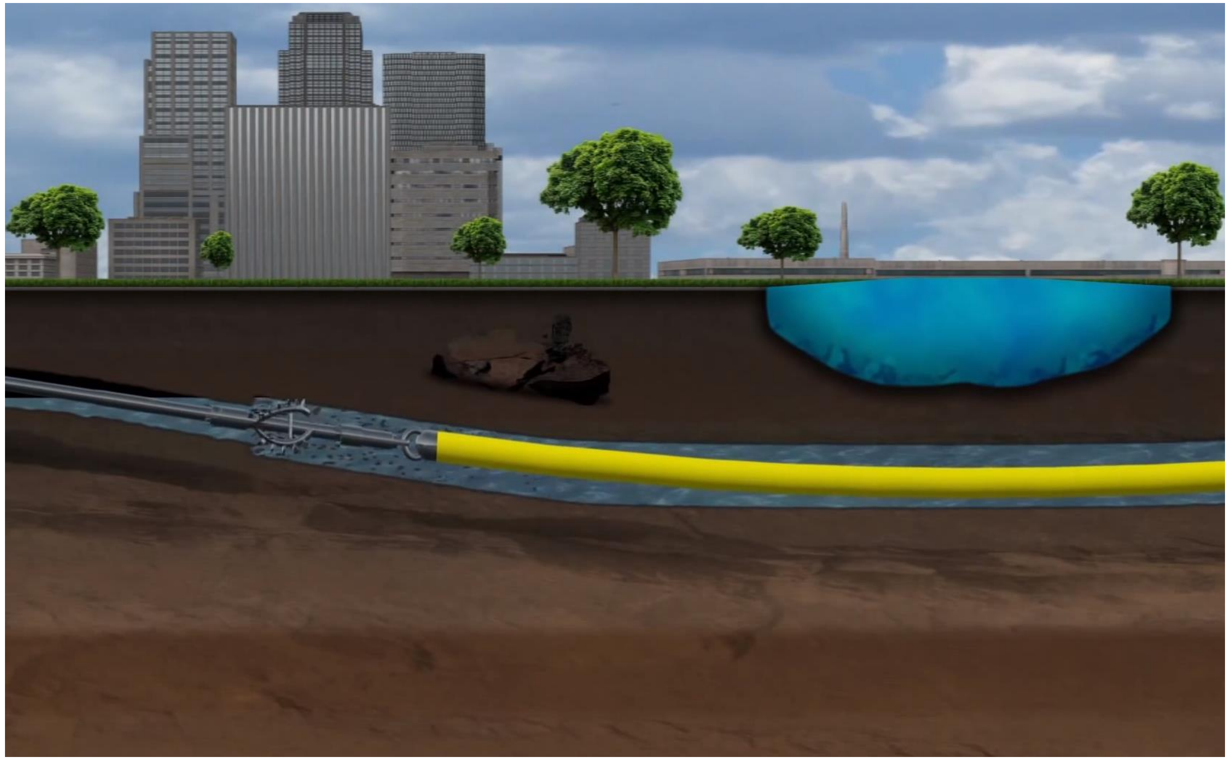
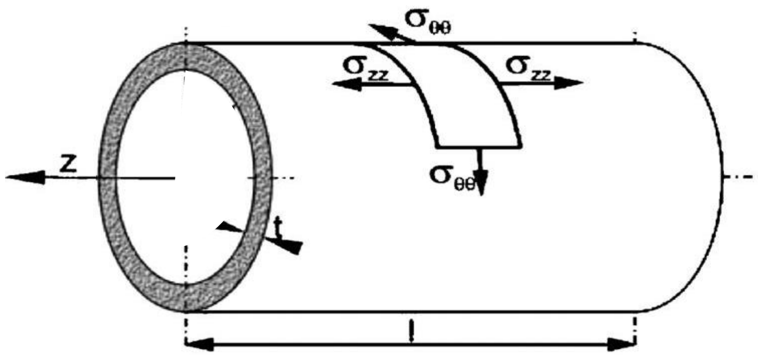
Summary of Design Parameters

Design Parameters	HDD 1	HDD 2
Pipe Outside Diameter (mm)	762	762
Pipe Wall Thickness (mm)	15.8	15.8
Pipe Grade (MPa)	483	483
Pipe Modulus of Elasticity (MPa)	207,000	207,000
Radius of Curvature (m)	900	900
Total Length of the Crossing (m)	1,112	1,389
Diameter of the Borehole (mm)	1067	1067
Drill Pipe Outside Diameter (mm)	139.7	139.7
Drill Pipe Wall Thickness (mm)	10.54	10.54
Drilling Fluid Density (kg/m^3)	1318	1378
Drilling Rig Size (lbs)	440,000	660,000
Fluidic Drag Coefficient (Pa)	172	172
Friction Coefficient - Pipe & Borehole	0.3	0.3
Friction Coefficient - Pipe & Ground	0.1	0.1

LOADING IMPOSED ON THE PIPELINE

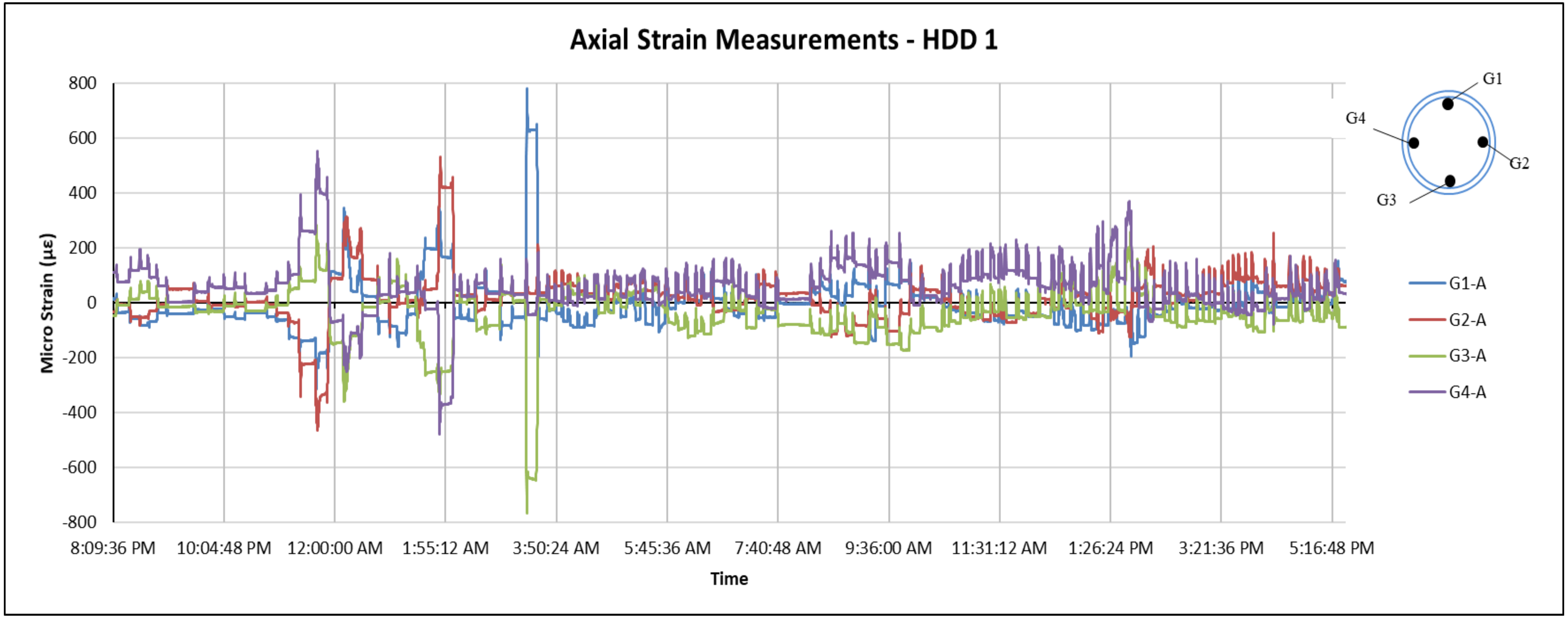
- Axial tensile stress from pulling force
- Axial bending stress from borehole curvature
- A net external (circumferential) hoop stress
- Corresponding Poisson's ratio effect of the axial and circumferential stresses
- A minor twisting moment due to the rotation of pipeline





MEASURED STRAINS

HDD 1



The maximum strains << elastic limit deformation of the pipe (0.5% or 5000 micro strain, με)

MEASURED STRAINS

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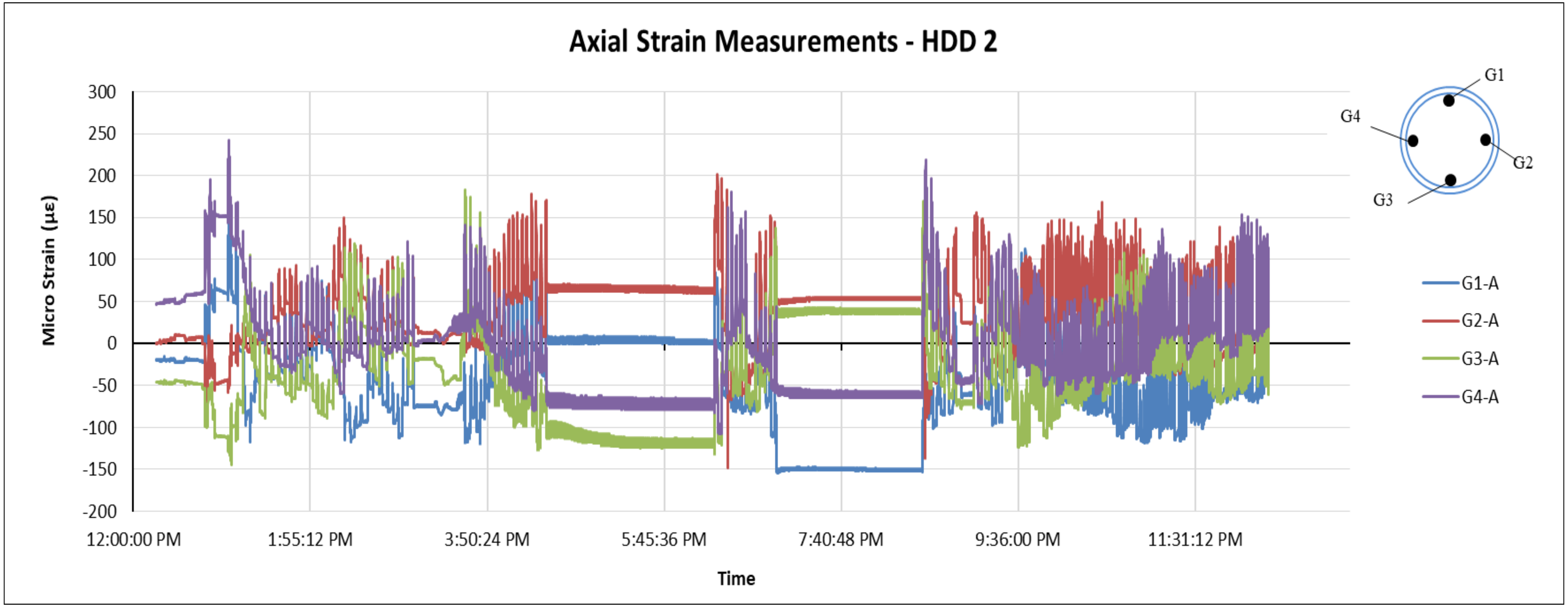
HDD 2



The maximum strains << elastic limit deformation of the pipe (0.5% or 5000 micro strain, με)

MEASURED STRAINS

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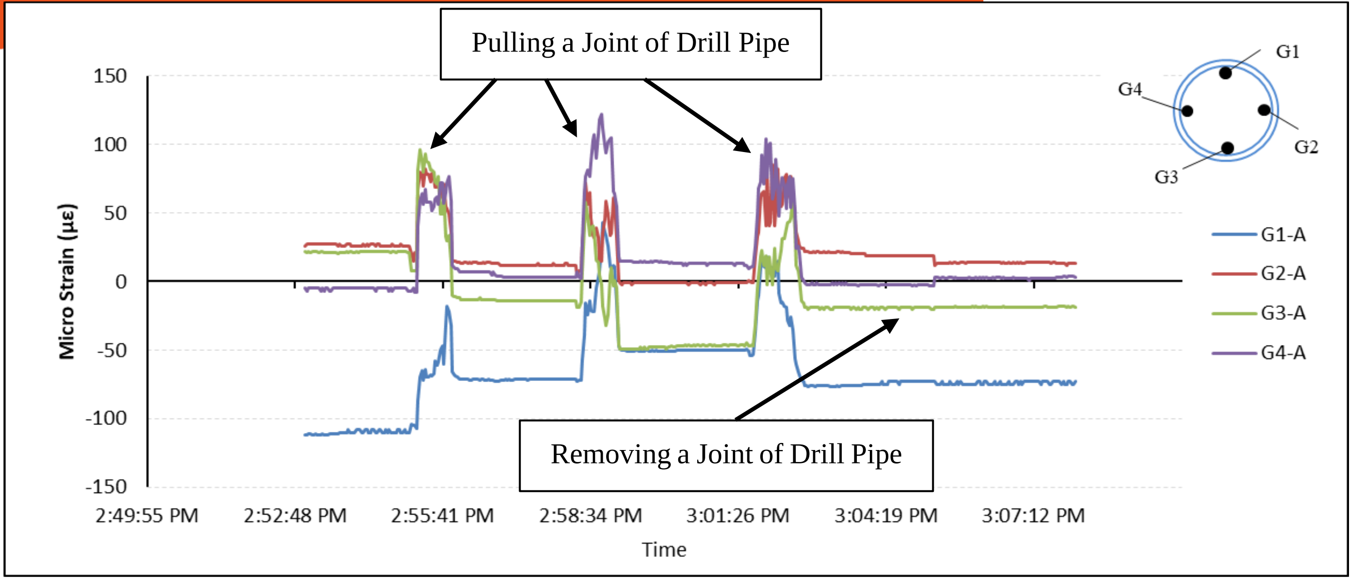
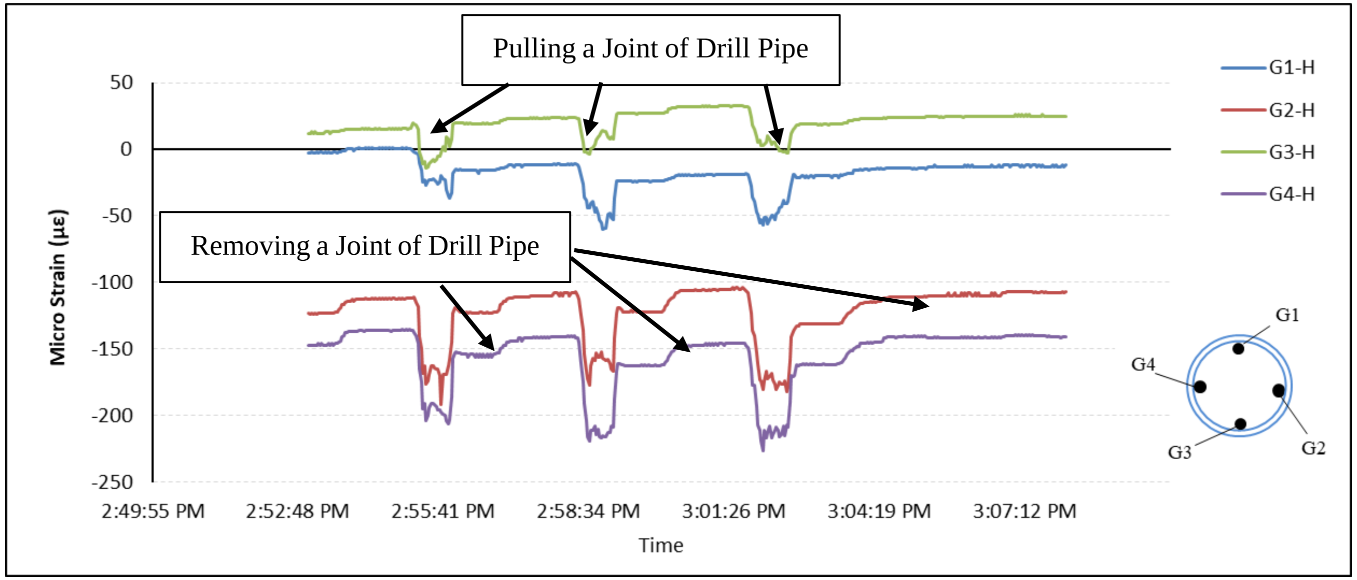
Axial Strain During Pulling 3 Joints of Drill Pipes



Circumferential Strain During Pulling 3 Joints of Drill Pipes

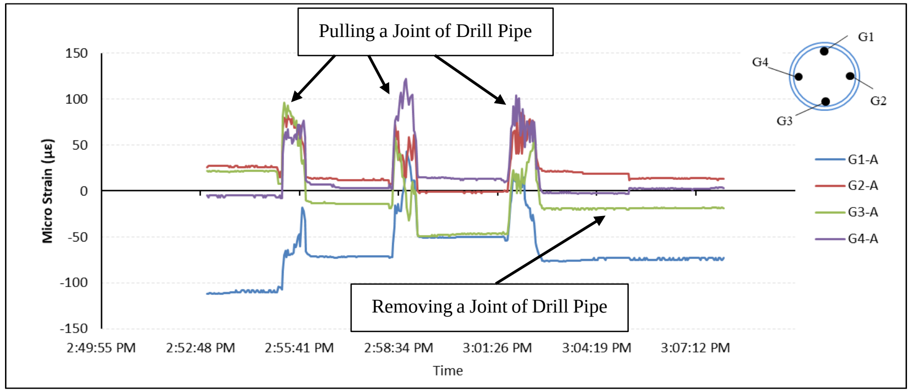


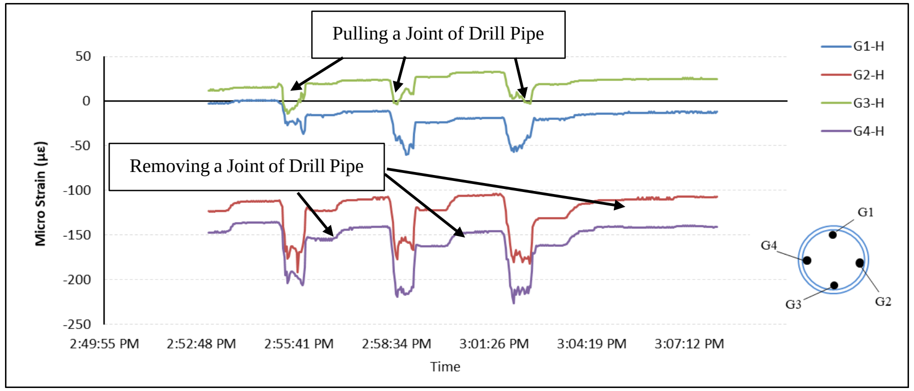
PULL FORCE IMPOSED ON THE PIPELINE

- The pull force results in an abrupt increase in axial tensile strain measured at the start of the pullback for each joint of drill pipe.
- The axial strain due to bending moments acting along the axis through each pair of gauges are expected to be equal but with opposite signs.

$$T_i = E\ A\ (\Delta\epsilon_1 + \Delta\epsilon_2 + \Delta\epsilon_3 + \Delta\epsilon_4\ )/4$$

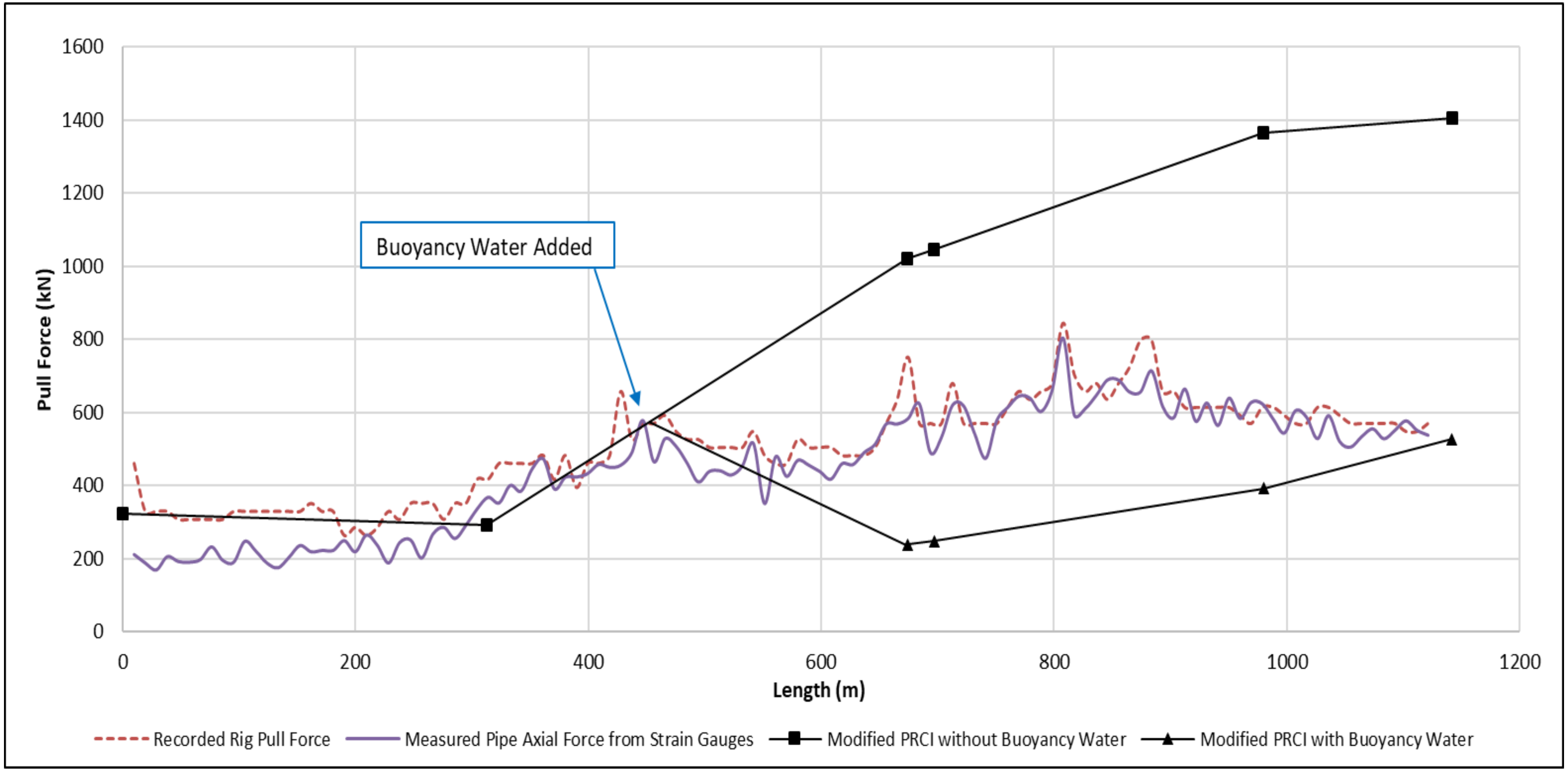
T_i - pull force exerted on the product pipe during pulling drill pipe joint "i"





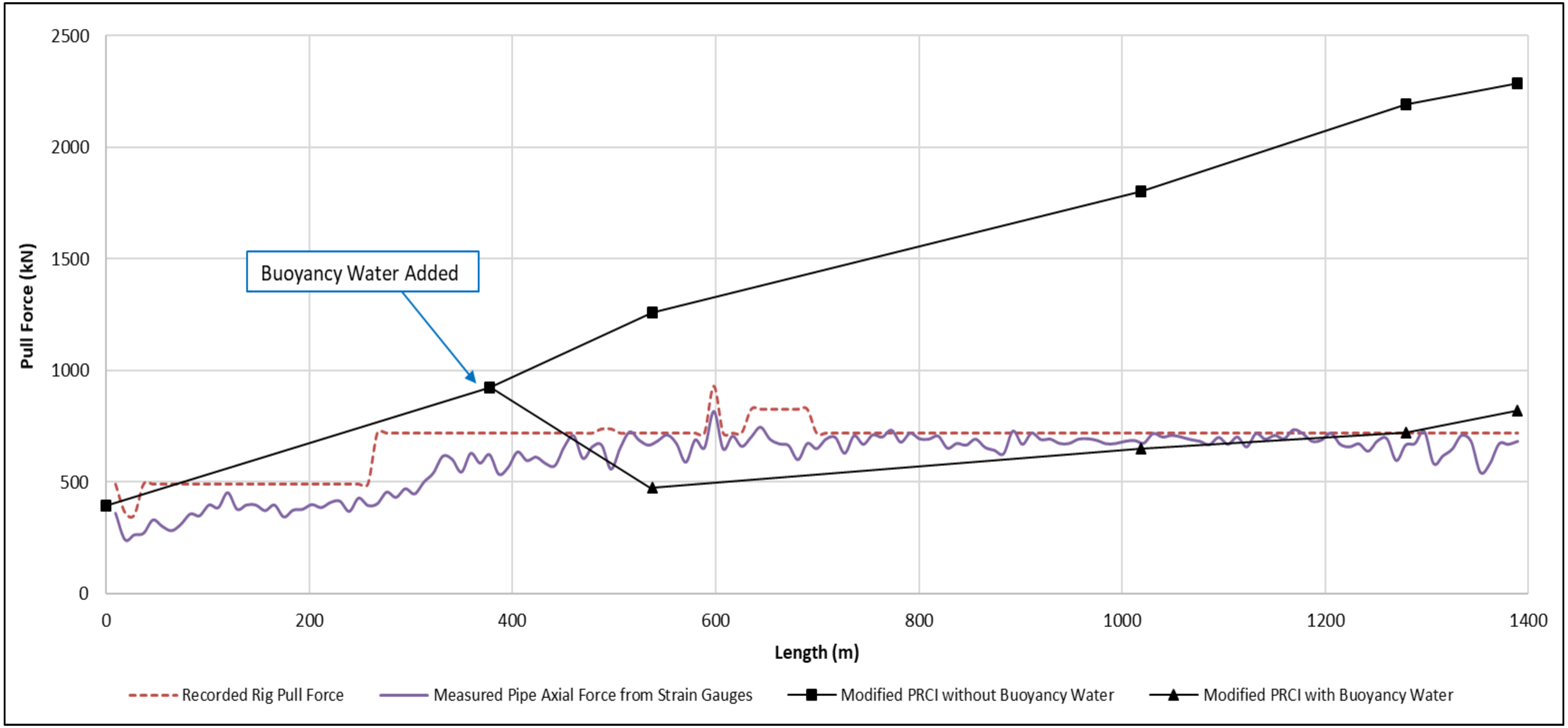
MEASURED AXIAL FORECE

Measured Axial Forces vs Theoretical Estimates and Recorded Rig Pull Force for **HDD 1**



MEASURED AXIAL FORECE

Measured Axial Forces vs Theoretical Estimates and Recorded Rig Pull Force for **HDD 2**



CONCLUSION

A review of over two hundred completed crossings showed that

- Theoretical estimations are more likely to overestimate the actual pull forces for crossings longer than 700 m, pipe sizes larger than NPS 20, and rig sizes larger than 625,000 lbs.
- Among the reviewed projects, most of the crossings with pipe sizes smaller than NPS 10 or rig sizes within 80,000 to 110,000 lbs were underestimated.
- Generally, theoretical predictions can be improved by assigning lower values of the borehole friction and mud friction factors to larger HDD projects and higher inputs for smaller installations.
- Also, engineering safety factors can be utilized based on the project scope and the quality of the construction execution.
- Safety Factors ranging from an upper limit value of 2.40 for smaller projects to a lower limit of 1.25 for larger projects to estimate the required rig force.

CONCLUSION

Based on the strain monitoring program, it was observed that:

- The measured axial force transferred to the pipe contributed to about 60% of the recorded rig force and their difference decreased as the pullback progressed.
- Many locations during the pullback were noted where the entire rig force was transferred to the product pipe.
- Buoyancy control utilized in both projects caused a reduction in pull forces which was captured by the measured forces.
- Theoretical calculations completed with and without internal water represented a lower and an upper limit for the actual forces to account for the partial buoyancy control during construction.
- Modified PRCI model with the addition of above ground friction considering full buoyancy and relatively heavy slurries showed close predictions to the measured axial forces at the end of the pullback.

THANK YOU

Questions?