Latest Advancements in DrillString Mechanics

SPE Gulf Coast Section – 03/09/2016

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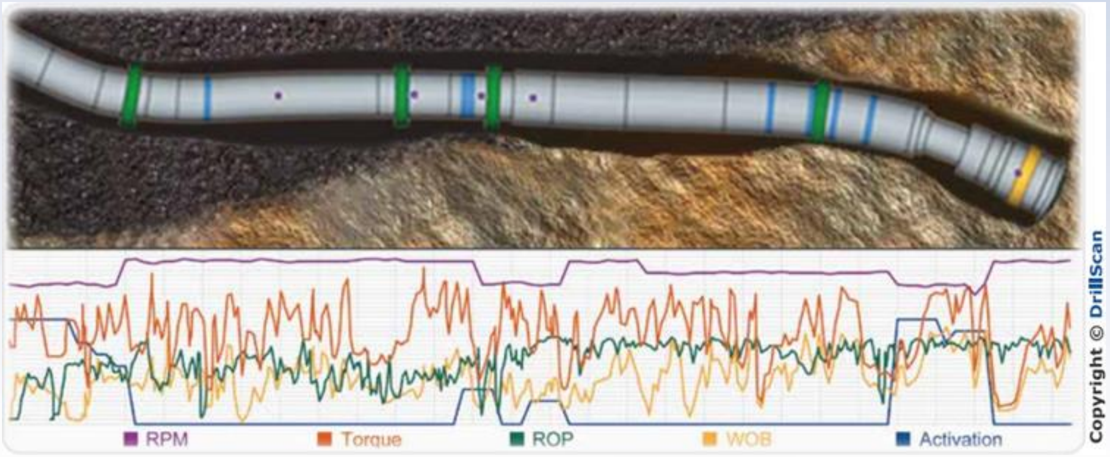
Outline of the presentation

- **DrillScan Intro**
- **Directional Drilling**
  - Problem Statement
  - Bit Steerability
  - Walking Tendency
  - Global vs Local Curvature
  - Unconventional Well Example
- **Torque & Drag & Buckling**
  - Soft versus Stiff String
  - Buckling Theory
  - Lab and Field Validation
  - Unconventional Well Example
- **Casing Wear**
  - Problem Statement
  - New Casing Wear model
  - Field Validation
- **Conclusion**

- **Expert Services, Innovative Software Solutions, Trainings for the drilling industry**
  - Directional Drilling, Torque & Drag & Buckling, Survey, Casing Wear, Fatigue, Drilling Bit Performance, Drilling Dynamics
- **Advanced Modeling Solutions**
- **Strong collaboration with Research**
  - Laboratory Validation & Permanent improvement
- **Strong collaboration with Operators**
  - Field Validation



Directional Drilling

BHA / Bit / Rock Coupling

The directional behaviour of any drilling system depends mainly on:

- **The Directional System:**
  - Rotary Steerable System (RSS)
  - BHA rotary
  - Steerable Mud Motor
  - With/without Reamer Capability

- **The Rock Formation:**
  - Hardness (UCS)
  - Anisotropy (dip angle)

- **The Drilling Bit Characteristics**
  - Walking tendency (Turn rate)
  - Steerability = Side-cutting ability (Build/Drop Rate)

Directional Drilling

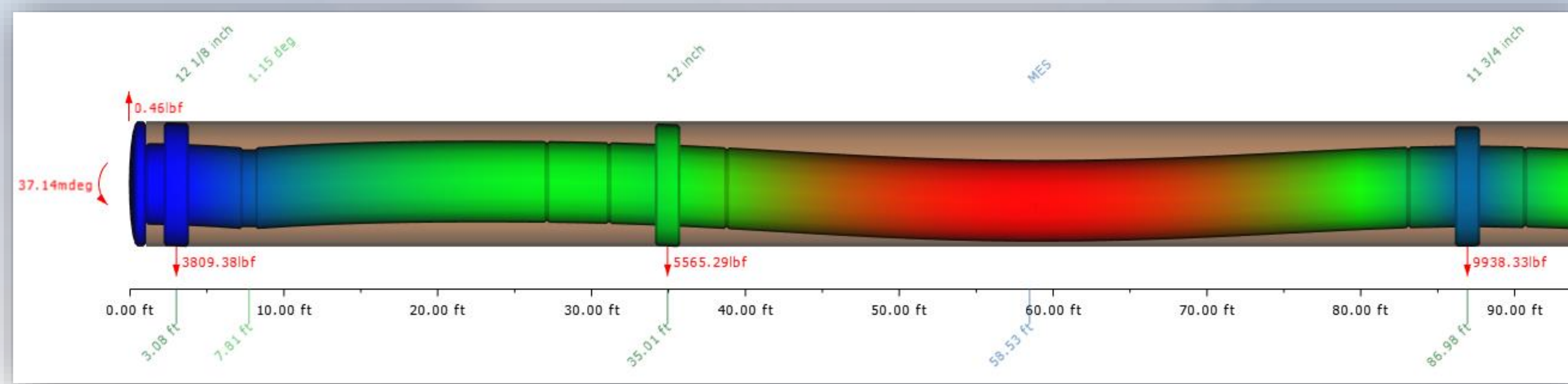
BHA / Bit / Rock Coupling

Rock-Bit model

+

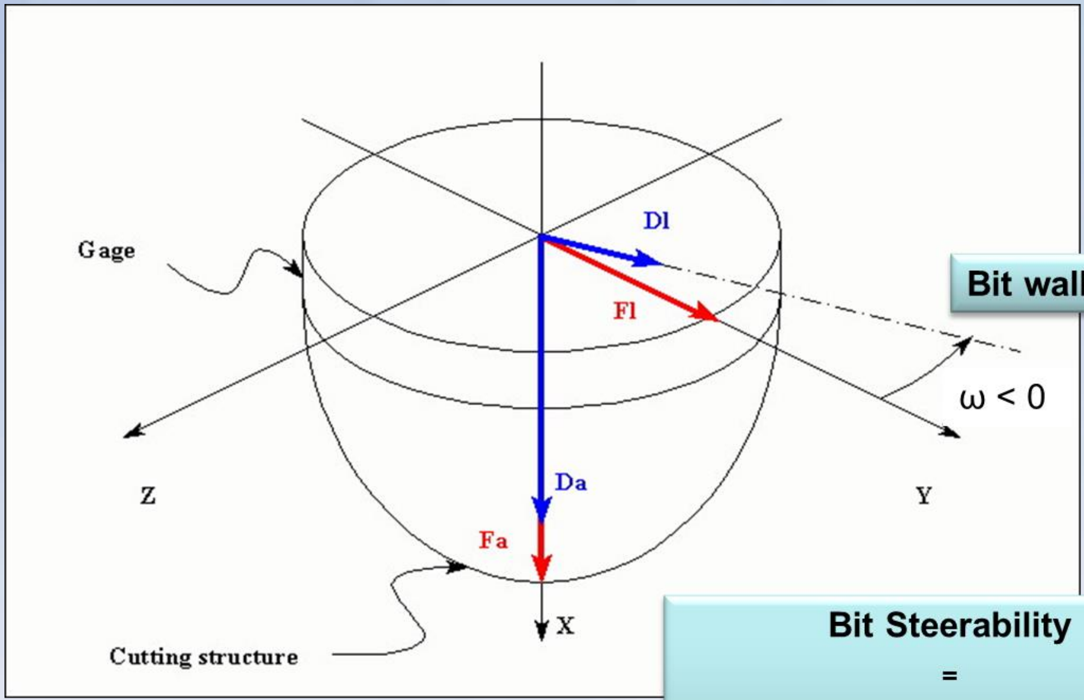
+

BHA model



SPE 74459, PA-82412, 79795, PA-87837, 110432

Bit Steerability & Walk Angle



Bit walk angle → Turn Rate

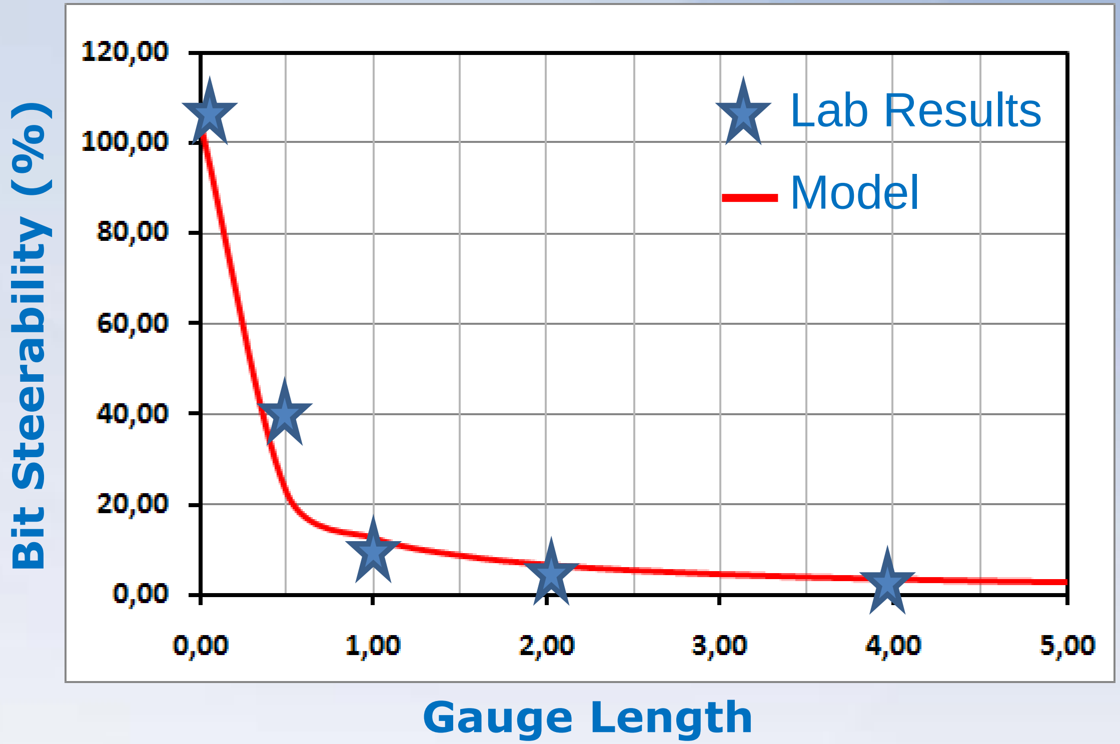
Bit Steerability
=
Lateral Drillability / Axial Drillability
=
(Dl/Fl) / (Da/Fa)

→ Build/Drop Rate

High Bit Steerability = High Side-Cutting ability of the bit

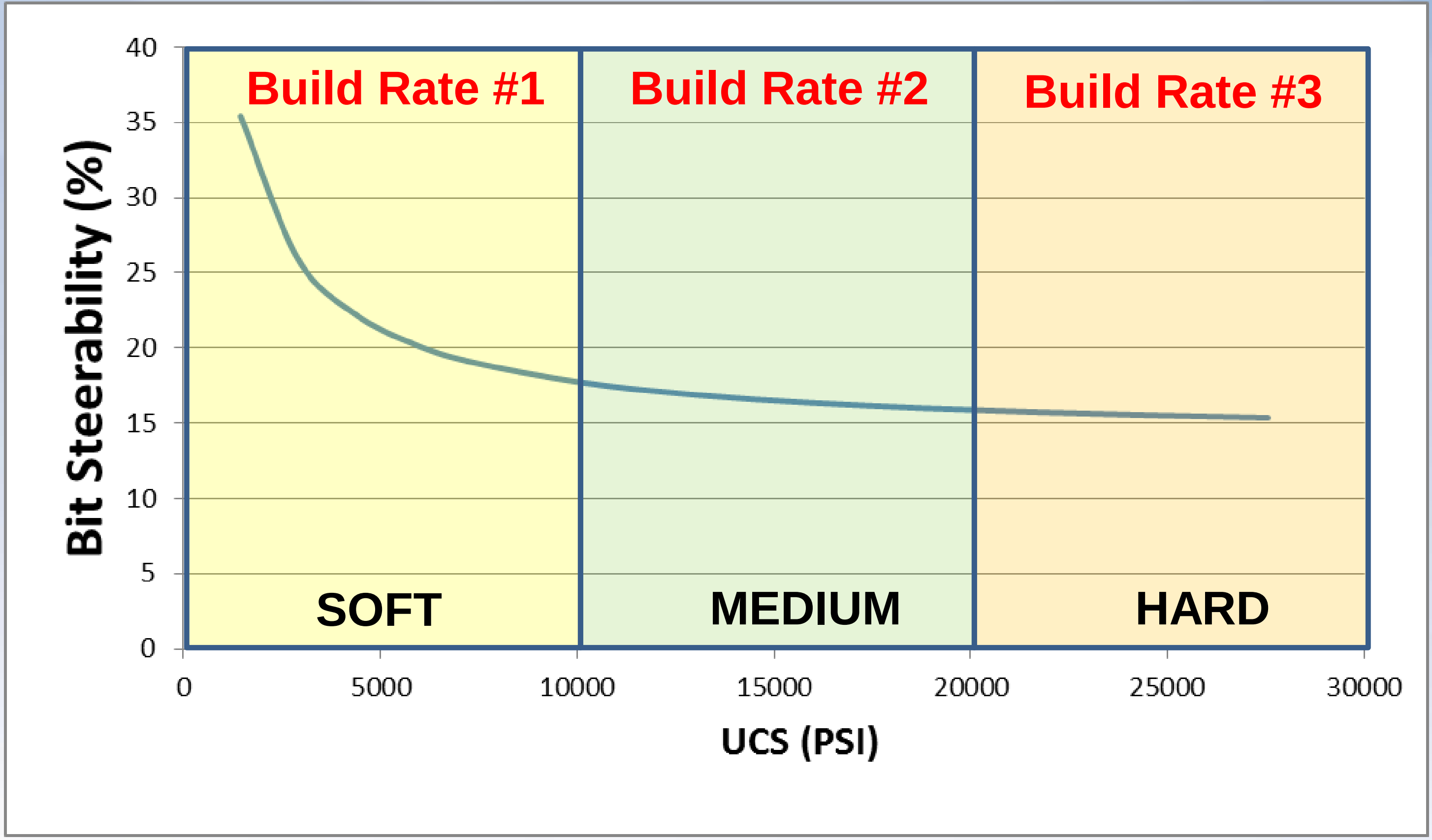
Bit Steerability = 5 - 50% for most PDC Bits

Effect of Gauge Length on Bit Steerability



SPE 74459, PA-82412, 79795, PA-87837, 110432, 151283

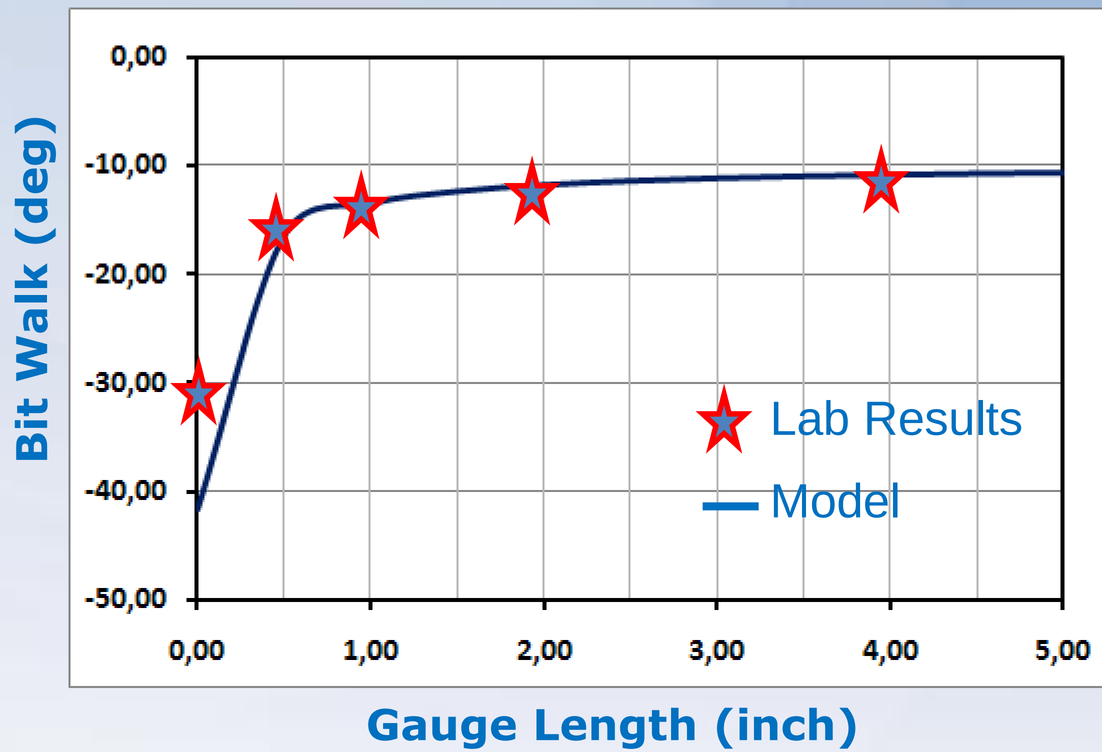
Effect of Rock Hardness



Higher Side-Cutting in a Soft Formation

Effect of Gauge Length on Bit Walk Angle

Gauge Length

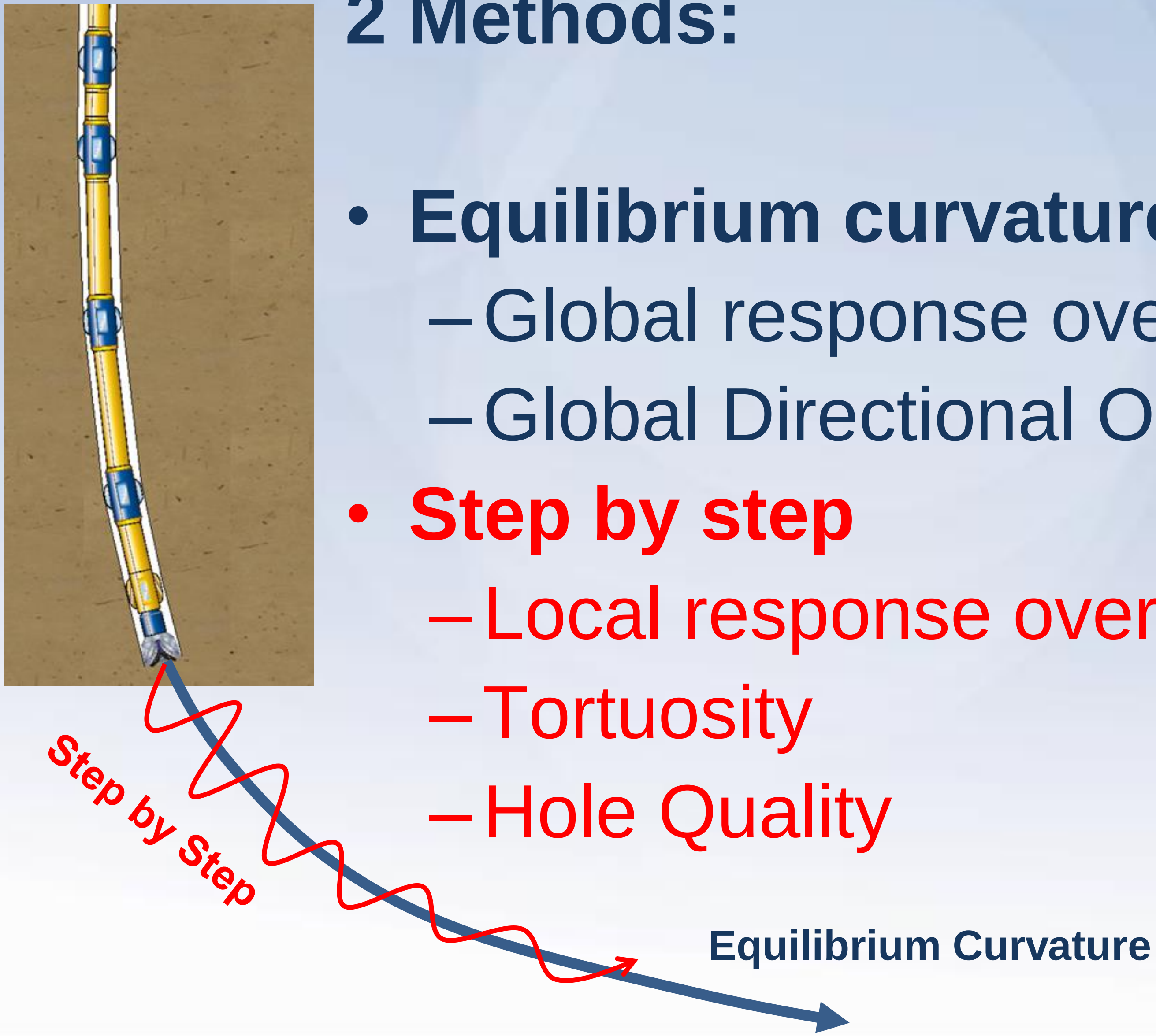


Tan (12 deg.) = 0.21 >> Coefficient of friction steel-rock

Generally speaking: if the coef. Of friction ↗ Bit Walk ↗ Turn Rate ↗

2 Methods:

- **Equilibrium curvature**
  - Global response over 100 ft or so
  - Global Directional Objective
- **Step by step**
  - Local response over 5 ft or so
  - Tortuosity
  - Hole Quality

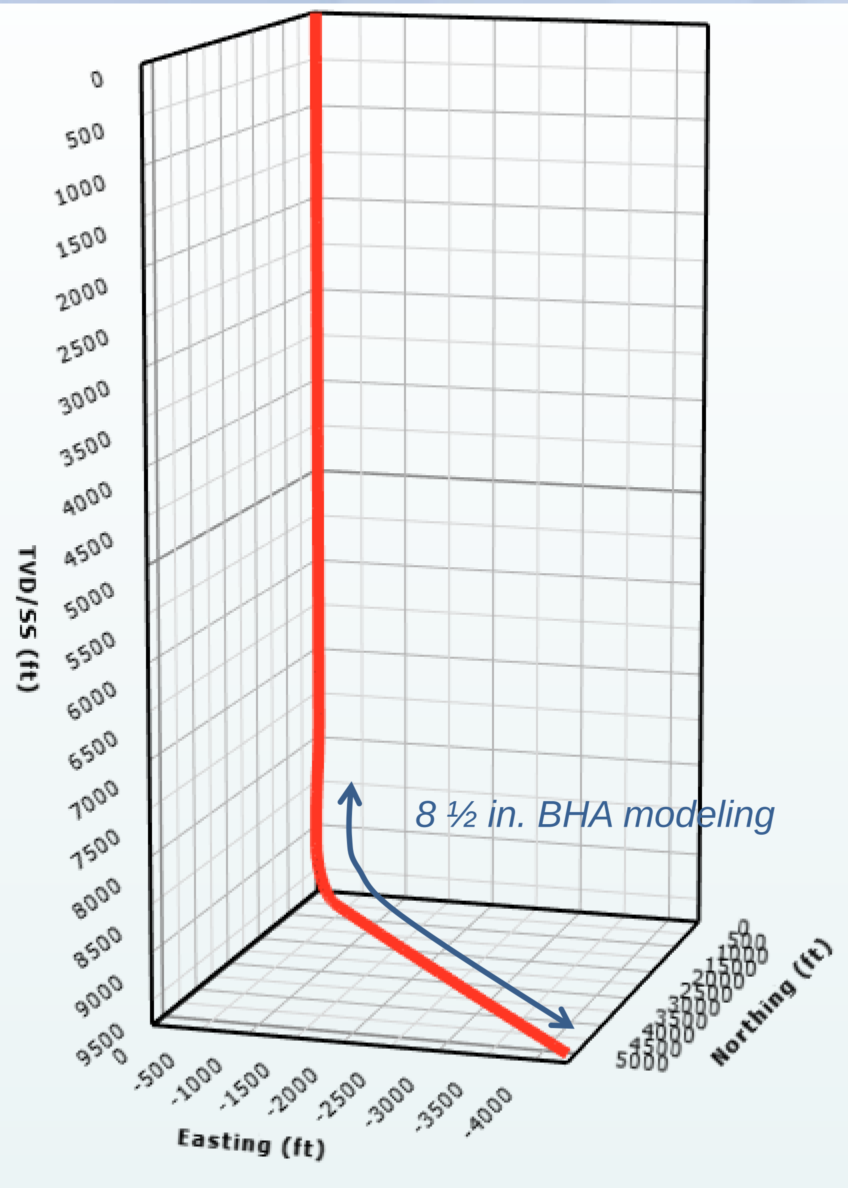


Required Data:

- **Well Trajectory**
- **BHA details**: ID, OD, Bend angle & position, Stabilizers, etc…
- **PDC bit specs**: Gage length, Bit Profile
- **Sliding/Steering sheet**: TFO, slide/rotate, activation level (RSS)
- **Mud weight**
- **Operating Parameters**: WOB, RPM
- **Rock**: Unconfined compressive strength (UCS)

Directional Drilling

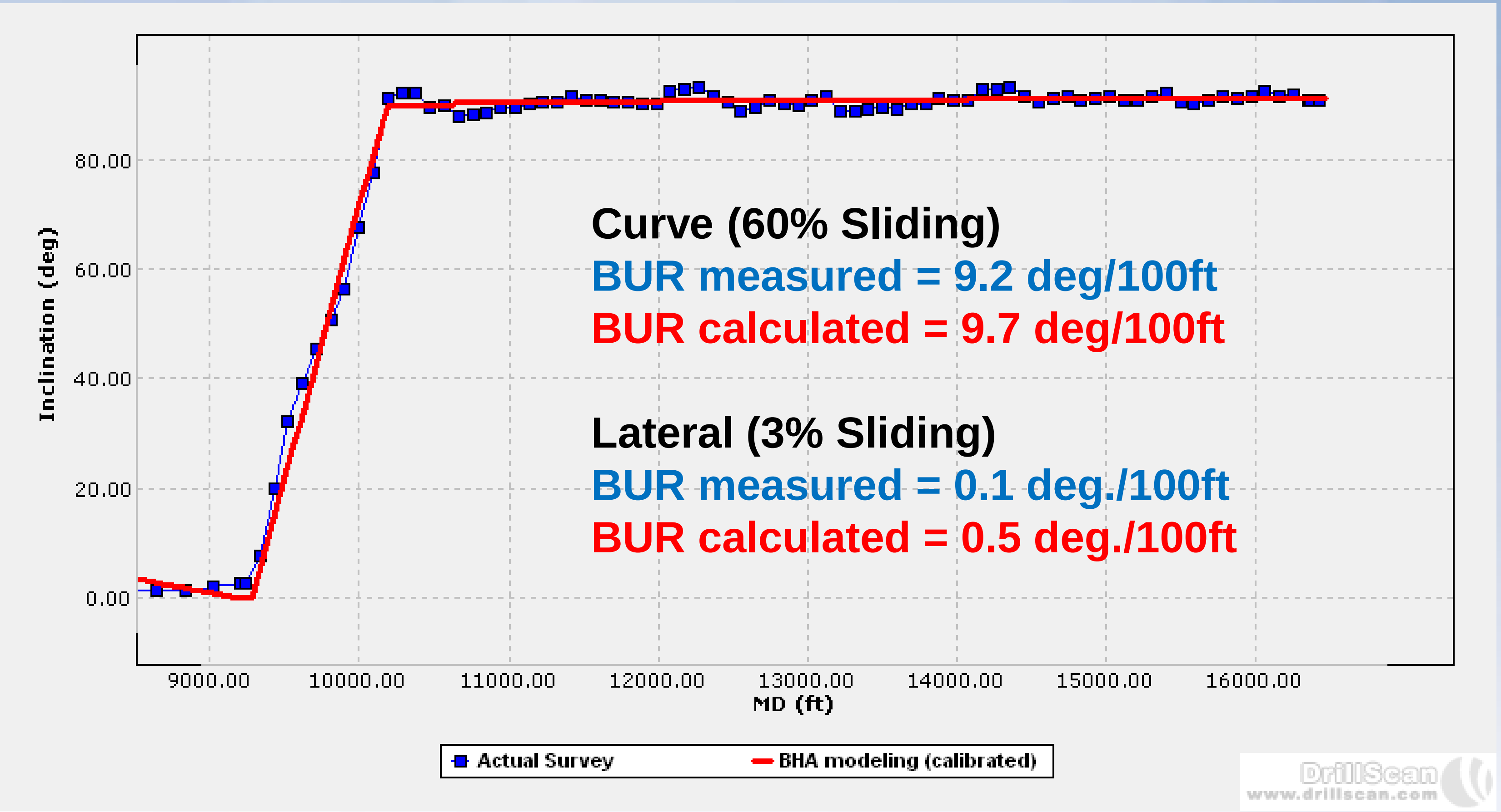
Case Study: Unconventional Well



- **Rock**
  - UCS = 7000 psi
- **8 ½ in. PDC Bit**
  - 2 inch Gauge Pad
  - Bit Steerability = 6%
  - Walk angle = -12 deg.

- **BHA**
  - Slick Assembly. 2 deg. bend
  - 7 in. 5/6 lobes Mud Motor
- **BHA modeling**
  - Curve + Lateral

Equilibrium approach = Global Curvature

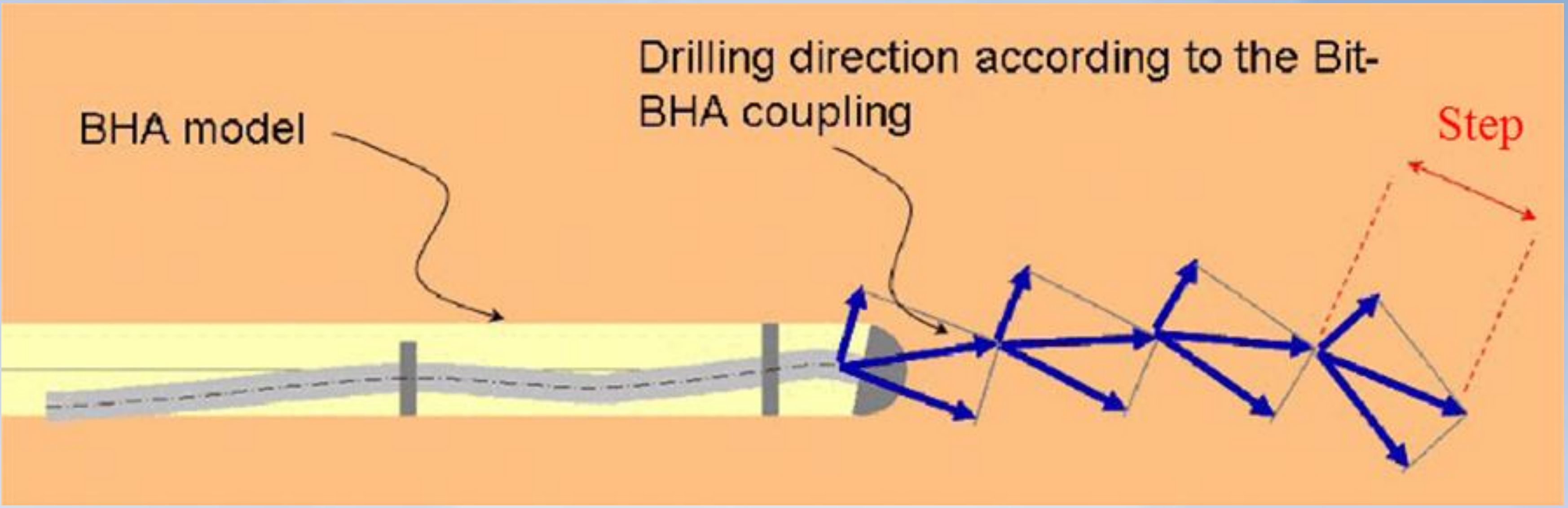


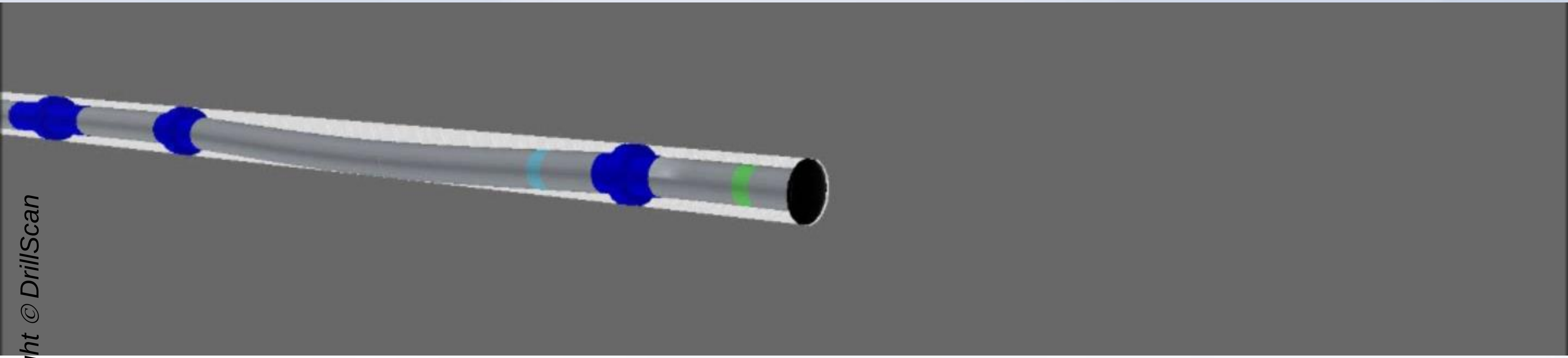
Reduction of Sliding in the Lateral Section >> Neutral BHA

If Slick Assembly = Gauge Length & WOB play a great role to make the BHA neutral

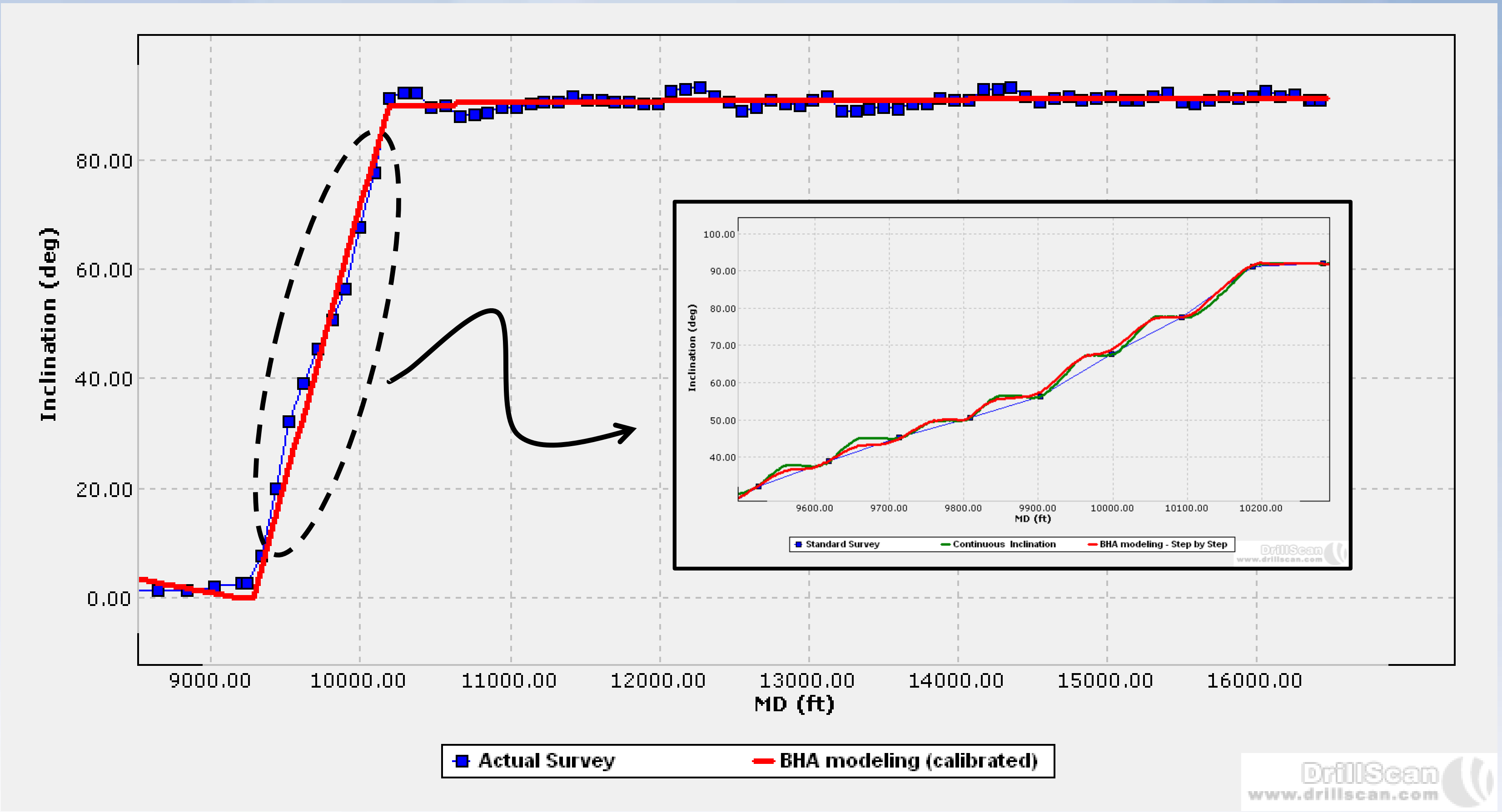
Directional Drilling

Step by Step Approach

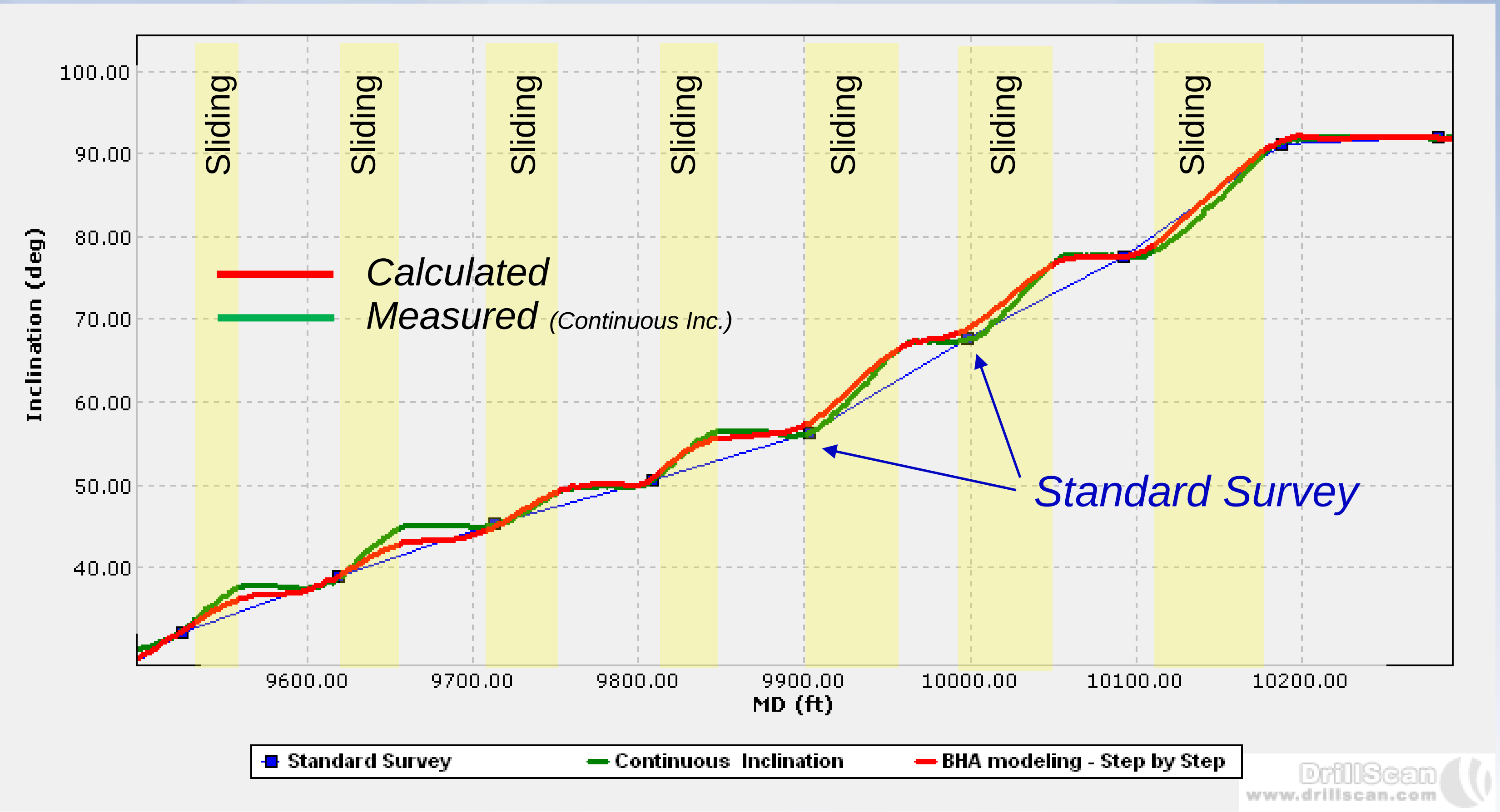




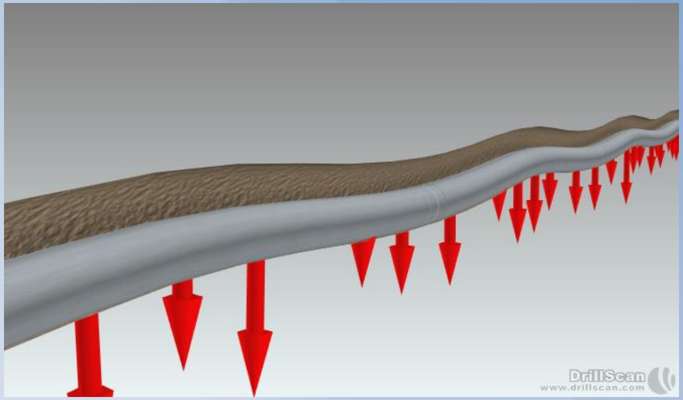
From Global Curvature to Local Dog Legs



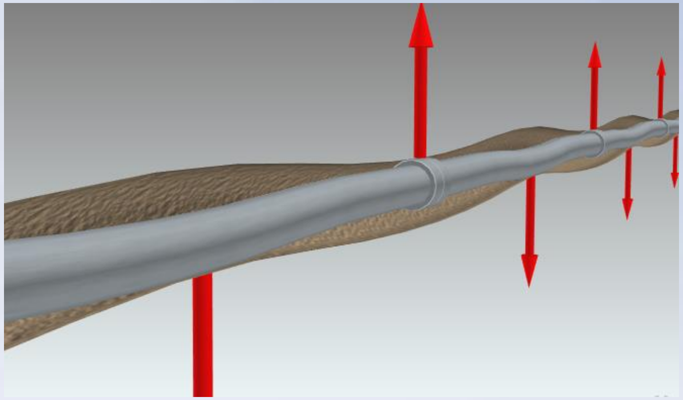
Step by Step Calculation vs Continuous Inclination Measurements



- Step by Step calculation
  - Borehole Tortuosity Evaluation
    - RSS / Steerable Mud Motor / BHA rotary
    - Fine tuning of the BHA to reduce tortuosity
  - Better Torque & Drag Prediction
    - More realistic tortuosity
  - Better Wellbore Placement
    - About 20 ft difference in TVD between Standard Survey vs Continuous Survey



- Soft-string model
  - *Johancsick et al*. (1983)
  - No Stiffness (it's a cable)
  - Continuous contact on the low side of the borehole



- Stiff-string model
  - *In collaboration with* MINES ParisTech
  - Stiffness
  - Unknown contact points computation

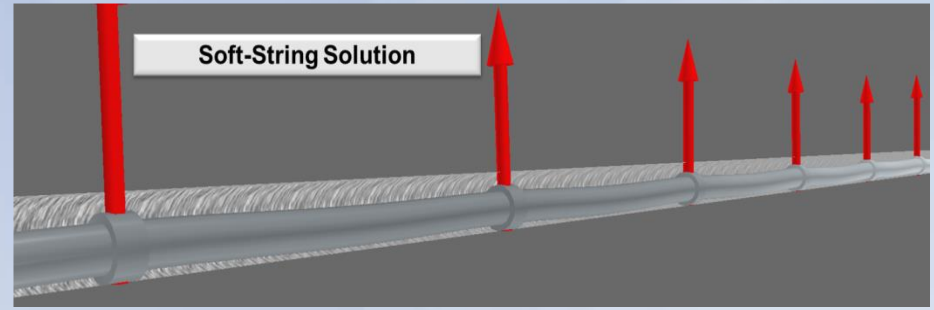
Torque & Drag & Buckling

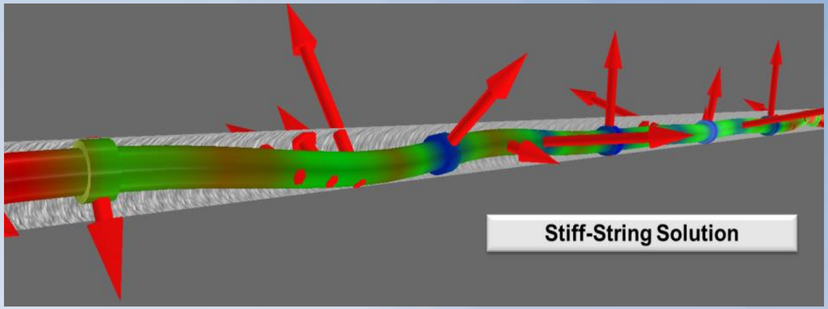
Drillstring Management

- *3D Stiff-string*
- *Fundamentals : Mines ParisTech*
  - *SPE 98965, SPE 102850-PA (modeling details), SPE 112571*
  - *SPE 119861, SPE 140211, SPE 151279*
- *Without FEA (Computation Time Reduced)*
- *Powerful Drillstring-Hole Interaction Contact Calculation*
- *Only provider of Simultaneous Torque-Drag-Buckling Calculation*
- *Any Type of Tubular Handled (beam element in 3D space)*
- *Hole Size and Clearance Effects*
- *Micro and Macro-Tortuosity Effects*

Torque & Drag & Buckling

Soft vs Stiff

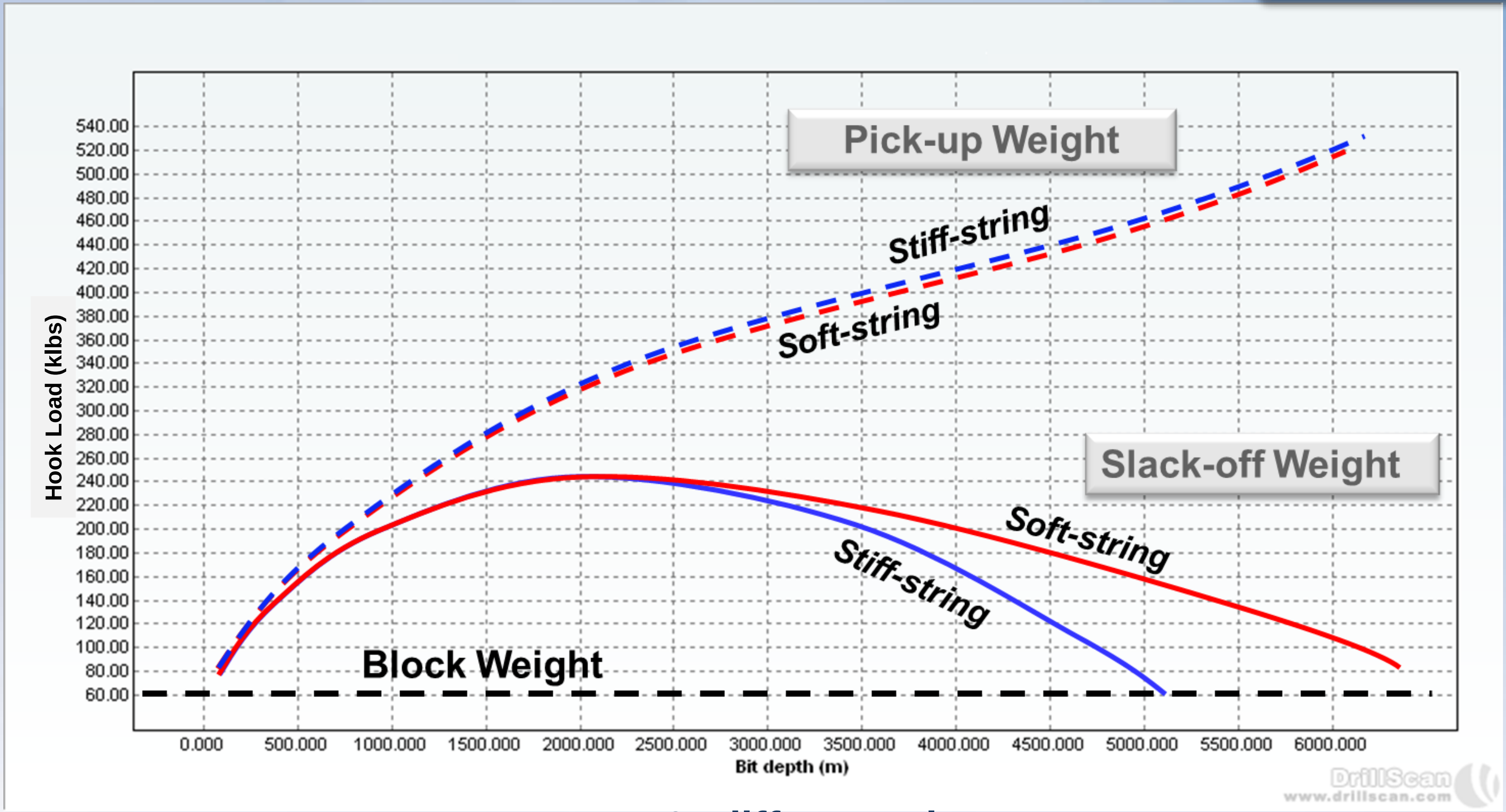




Engineering Features	Soft-string	Stiff-string
Clearance / Hole Size	✘	✔
Stiffness / Bending	✘	✔
Contact Calculation	✔ ✘	✔
Post-Buckling Calculation	✘	✔
Mechanical Integrity	✘	✔

Torque & Drag & Buckling

Soft vs Stiff



Up to 5% difference in PUW

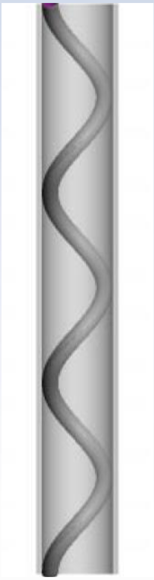
Up to 20% difference in SOW

Up to 30% difference in Torque

Up to 50% difference for Post-Buckling Calculation

Sinusoidal

$$Fc = 2\sqrt{\frac{EI\omega \sin(Inc)}{r}}$$



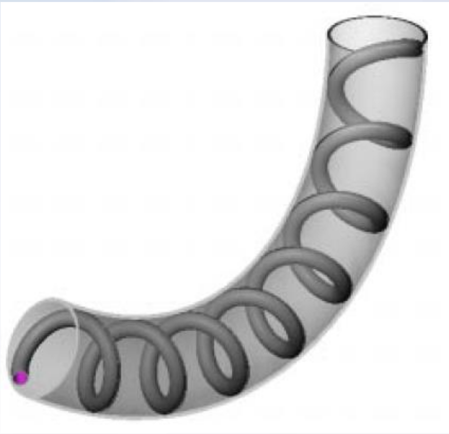
Helical

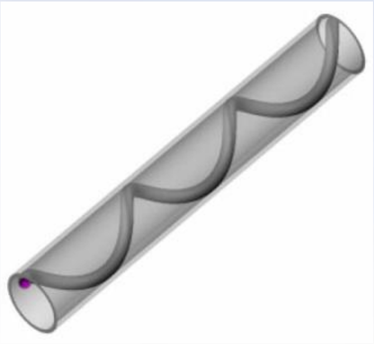
$$Fc = \lambda\sqrt{\frac{EI\omega \sin(Inc)}{r}}$$

$\lambda = 2\sqrt{2} = 2.83$............*Chen & Cheatham*

$\lambda = 2(2\sqrt{2}-1) = 3.65$...*Dawson & Paslay*

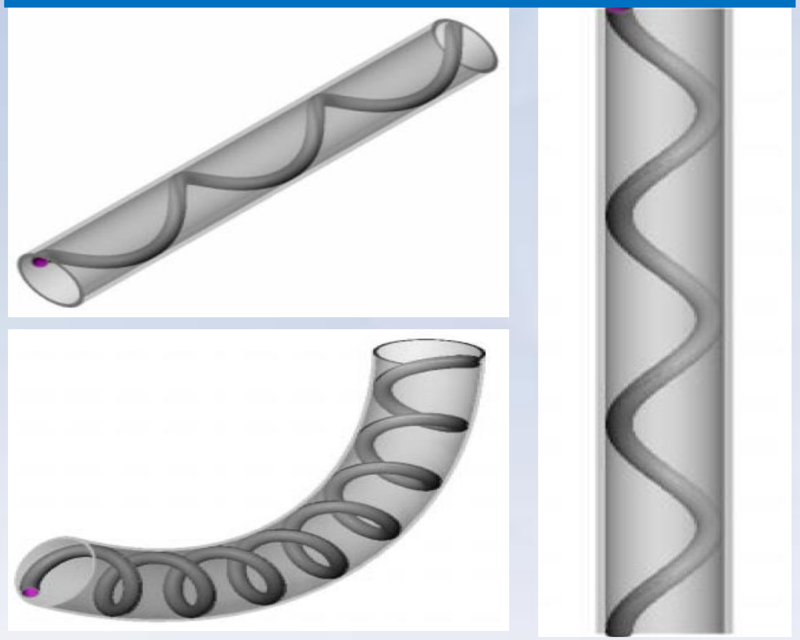
$\lambda = 4\sqrt{2} = 5.65$............*Mitchell*





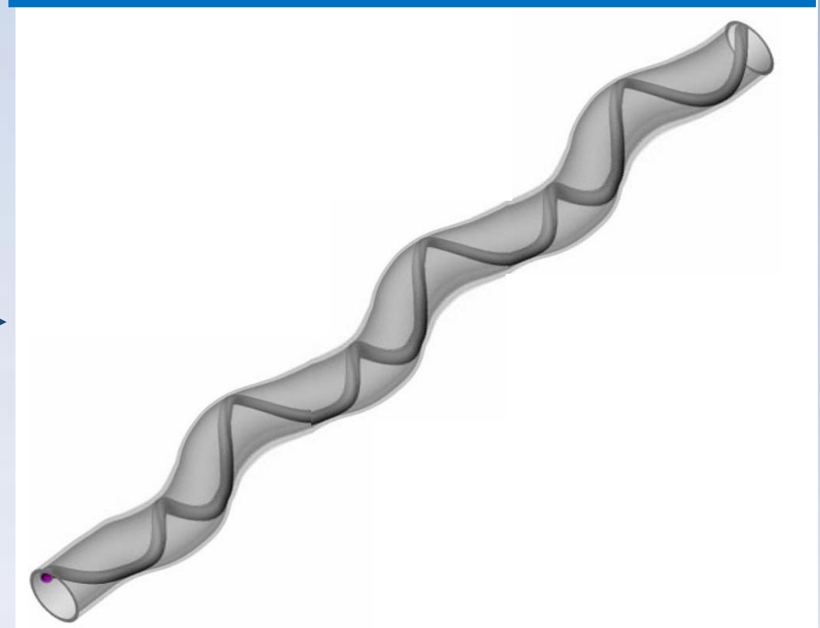
Standard Buckling Criteria

Idealized Case



Advanced Buckling Modeling

Field Conditions



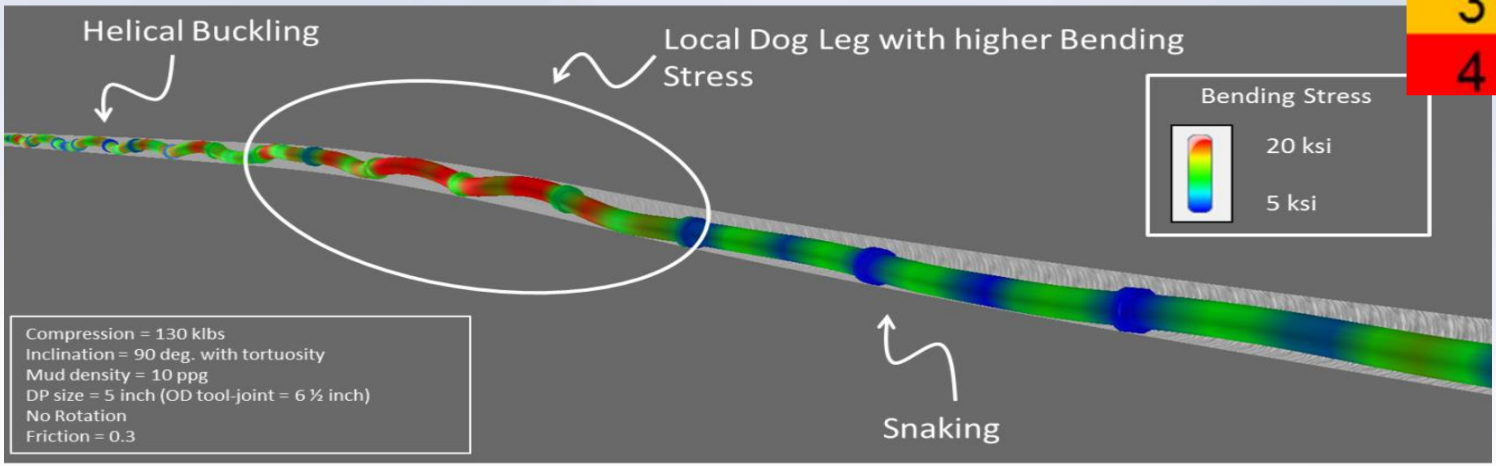
Rotation, Friction and Dog Legs have a great effect on Buckling

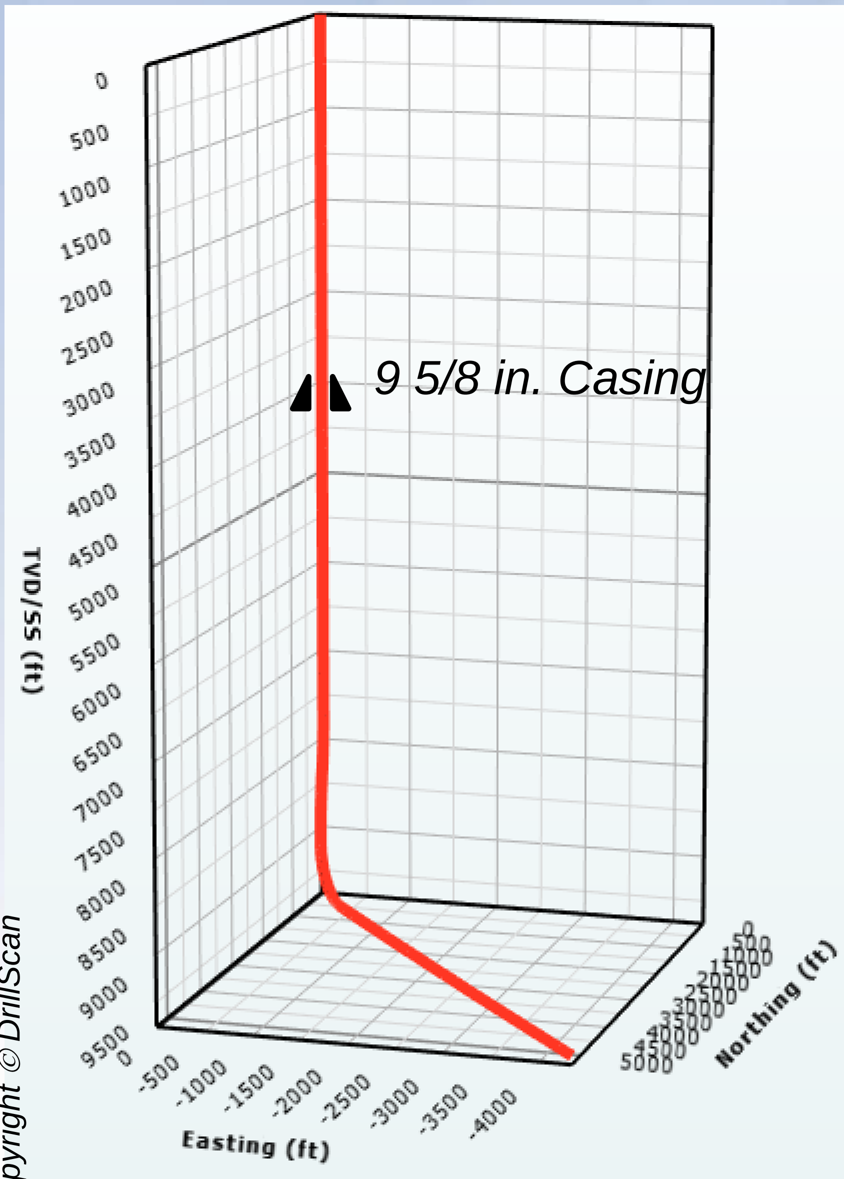
Torque & Drag & Buckling

New Buckling Criteria: Buckling Severity Index

- Laboratory and Field evidences have shown that standard Buckling Theories fail sometimes to predict Buckling
  - Ref: SPE 102850, SPE 112571, SPE 119861
- Drilling or tripping in the hole in exceeding standard buckling loads is still possible (reasonable bending stress level): Shale Gas Wells
- New criterion based on the **pipe stress** rather than the **pipe shape**
- **Buckling Severity Index** (BSI)
  - Ref: SPE 151279, SPE 151283

1	Low Risk
2	Medium Risk
3	High Risk
4	Severe Risk



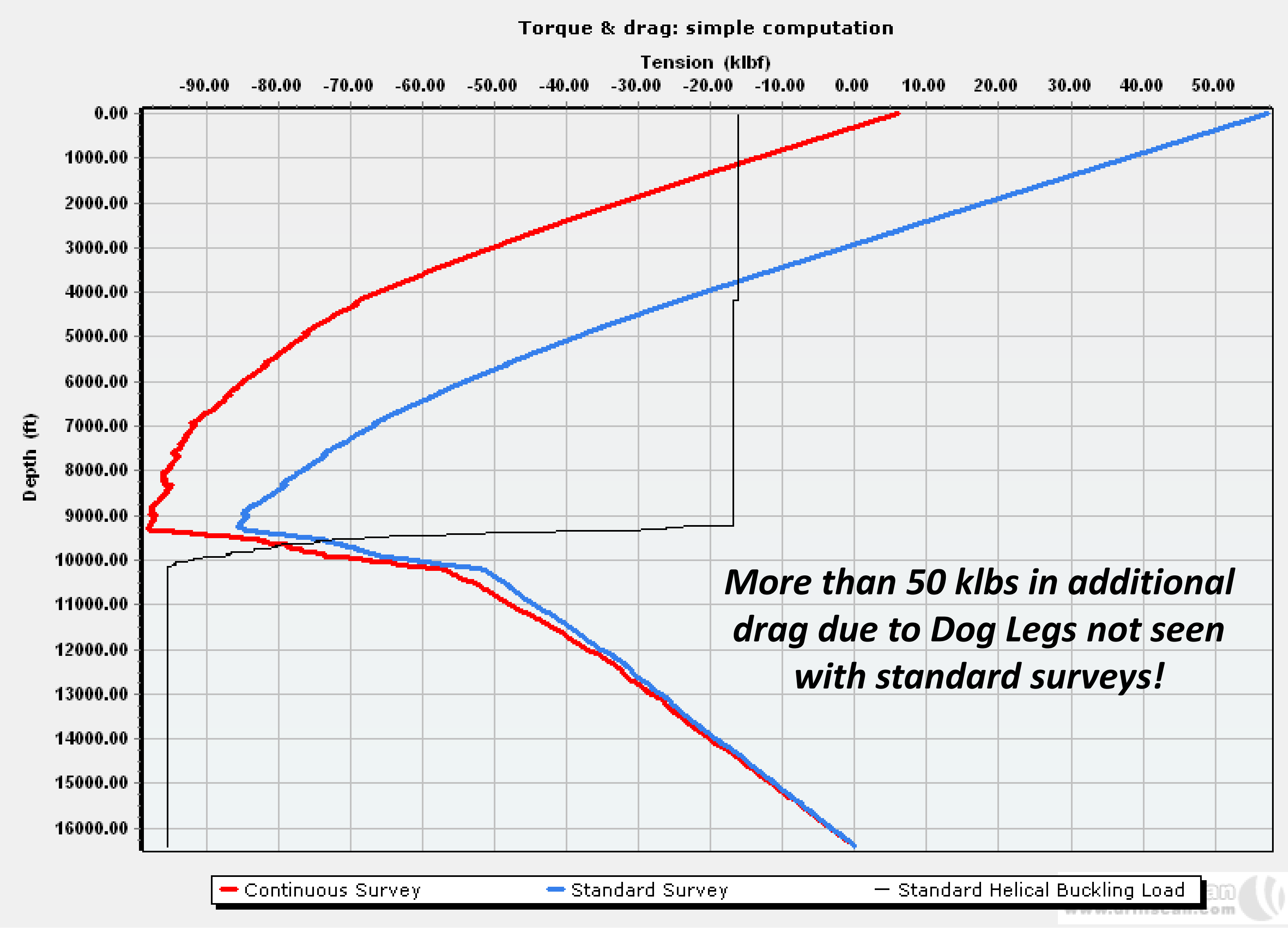


- **Run In Hole Simulation**
  - 5 ½ Casing String
  - Linear Weight = 23 ppf
  - Mud weight = 11 ppg
  - Coefficient of Friction
    - 0.20 in Cased Hole
    - 0.38 in Open Hole
- **Comparison**
  - Standard vs Continuous Survey
  - Soft-string vs Stiff-string
  - New Buckling Severity Index

Torque & Drag & Buckling

Case Study: Unconventional Well

Stiff-String Model



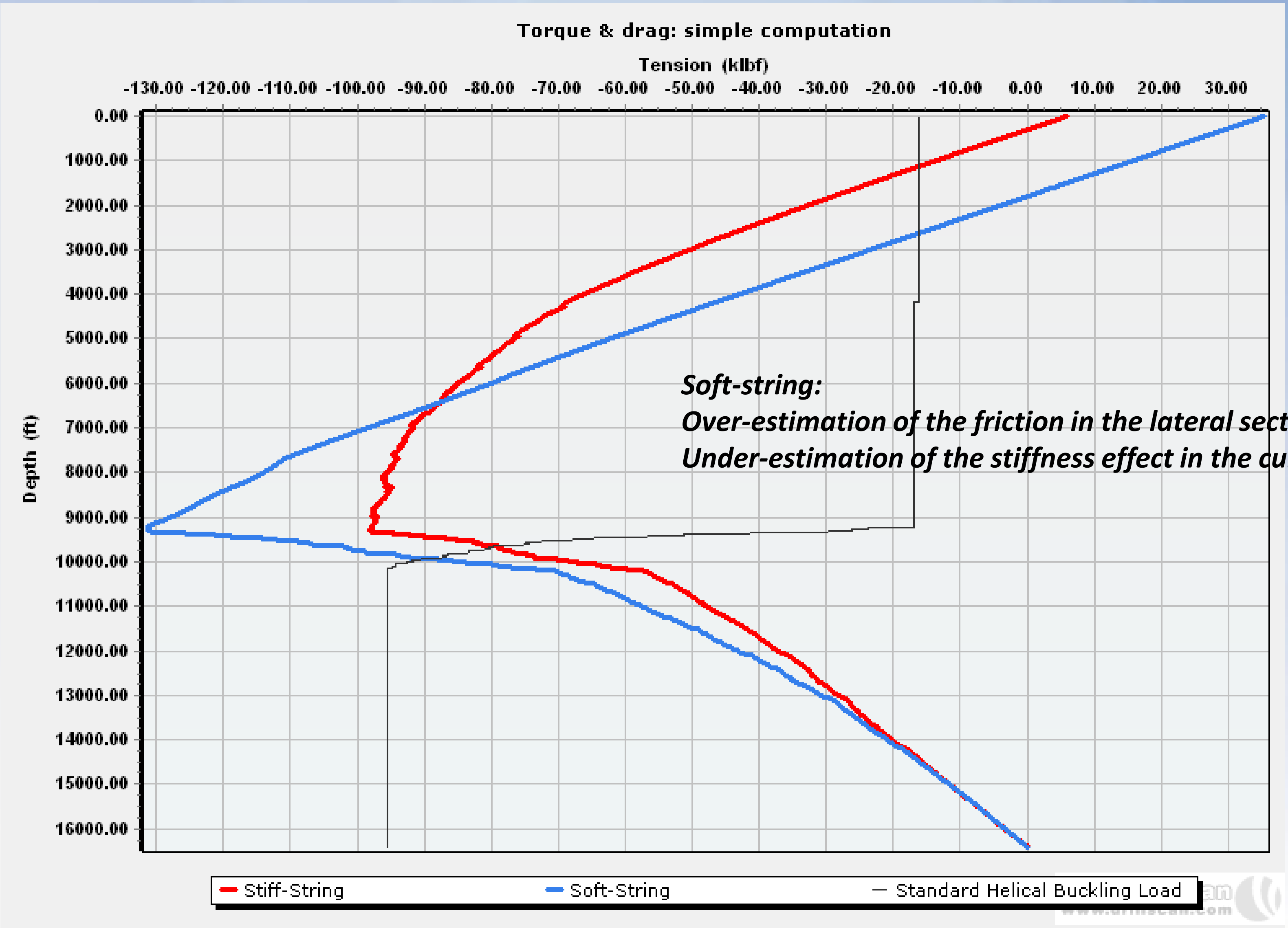
More than 50 klbs in additional drag due to Dog Legs not seen with standard surveys!

Torque & Drag & Buckling

Stiff-String vs Soft-String Model

Continuous Surveys

Case Study: Unconventional Well

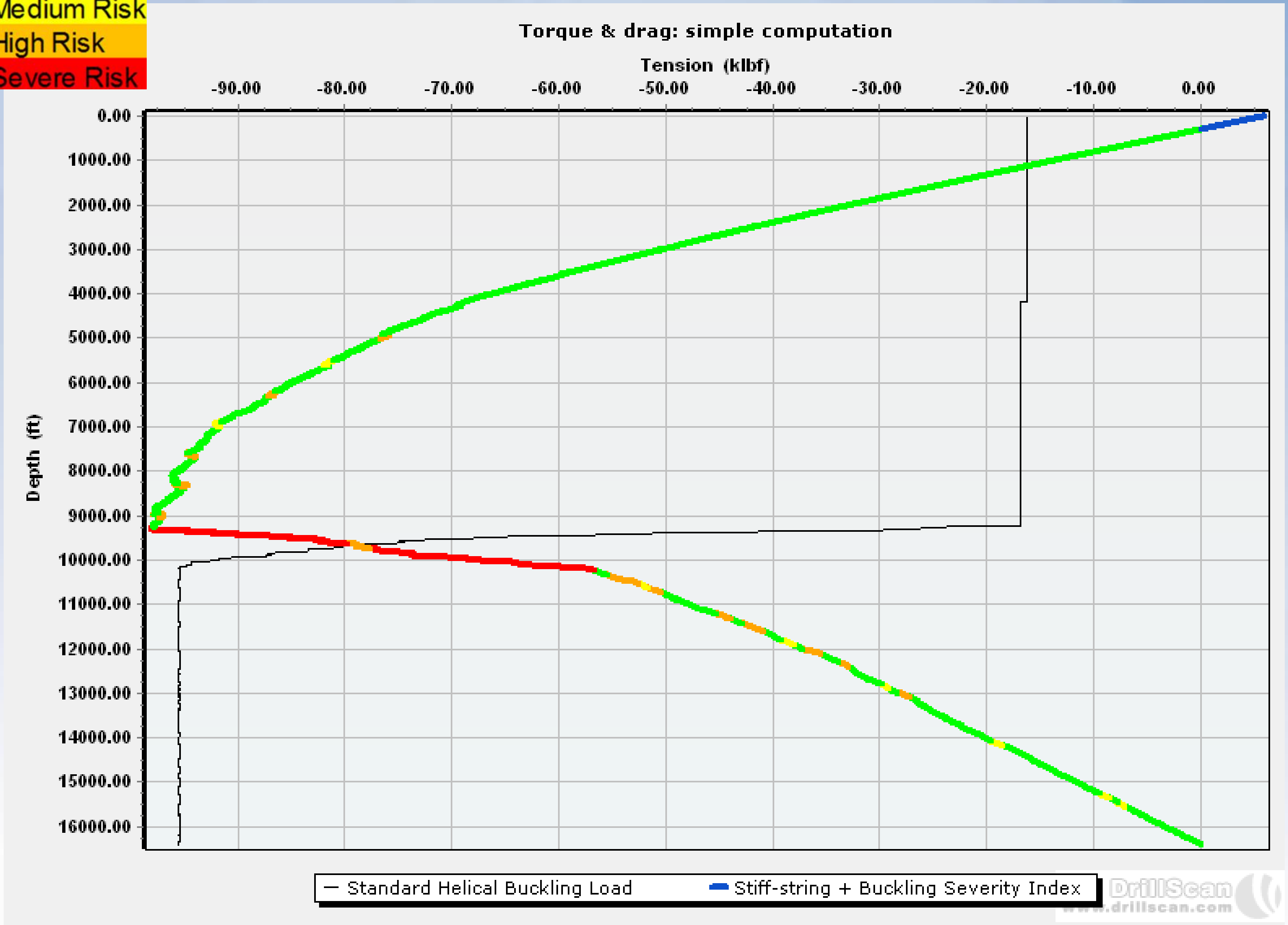


Torque & Drag & Buckling

Case Study: Unconventional Well

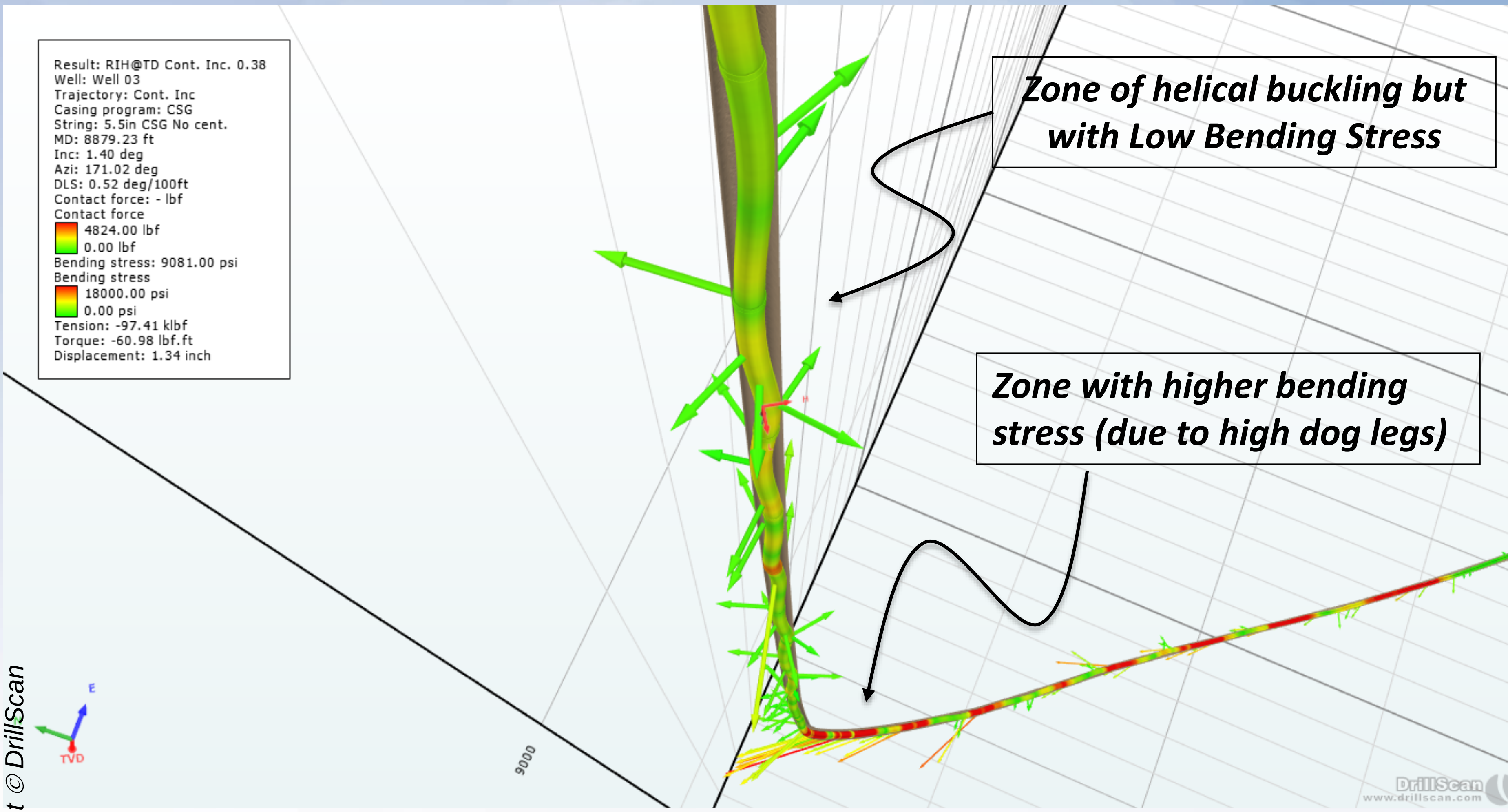
Buckling Severity Index

1	Low Risk
2	Medium Risk
3	High Risk
4	Severe Risk



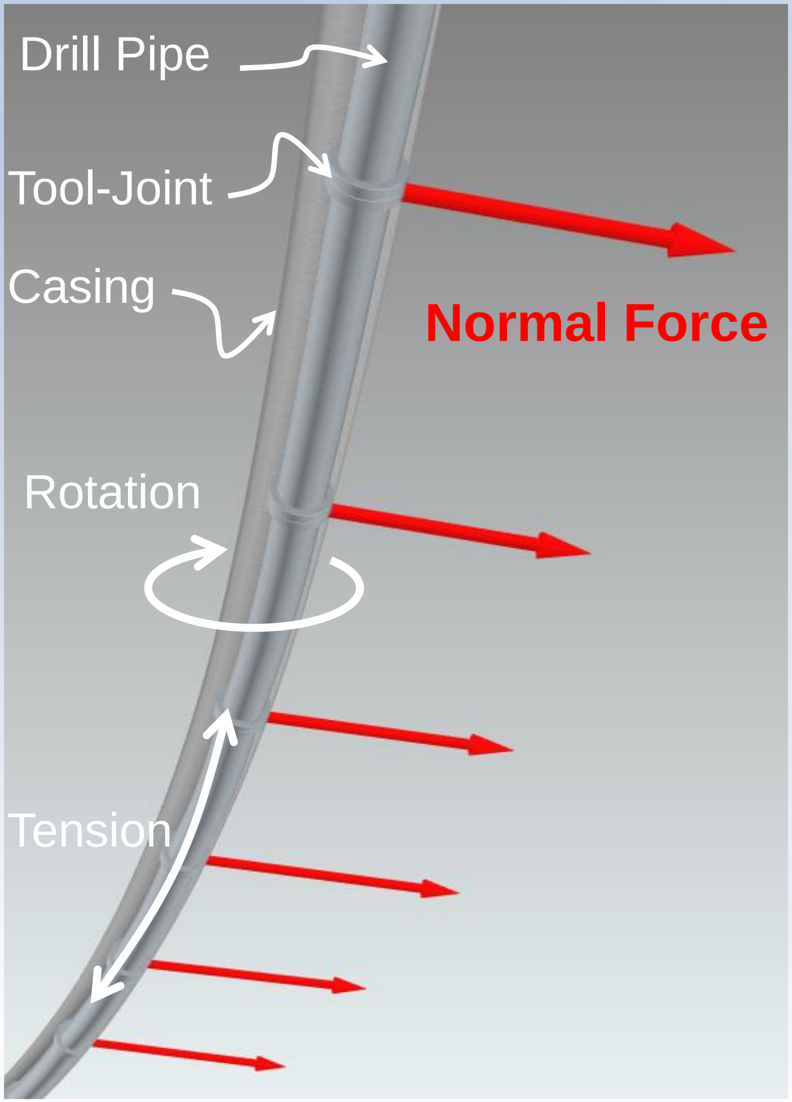
Torque & Drag & Buckling

Case Study: Unconventional Well



Casing Wear

Problem Statement

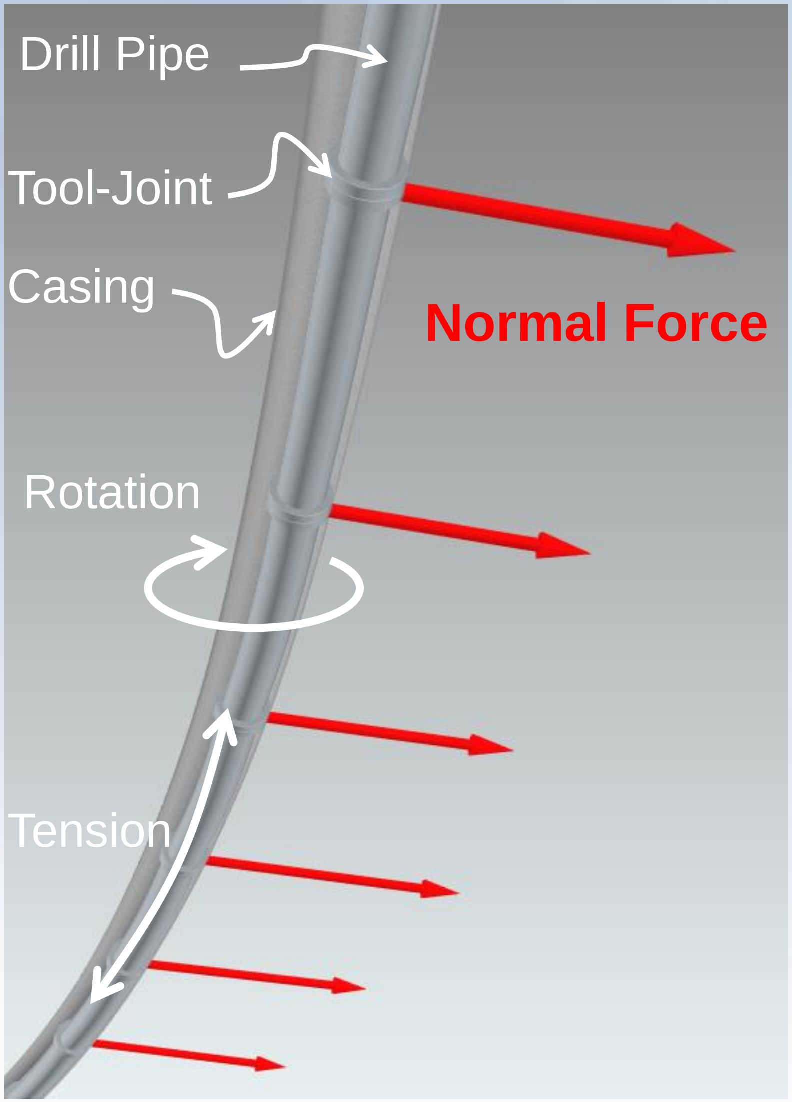


Casing Wear

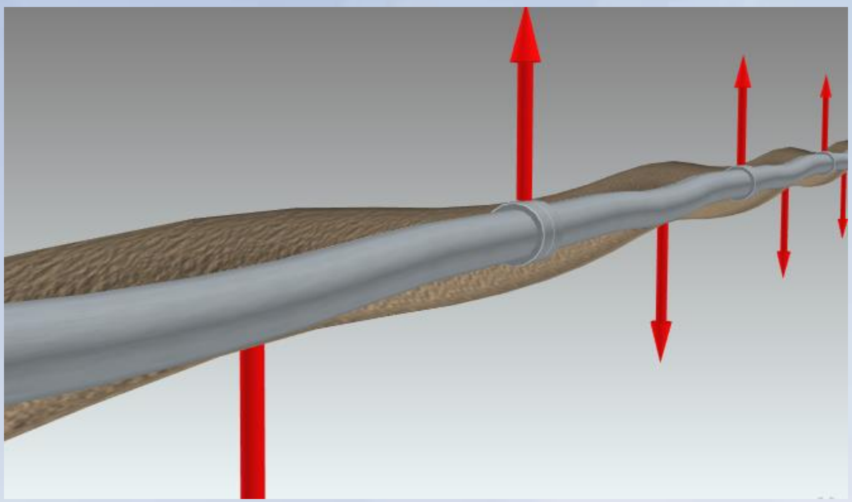
Tool Joint Wear

Casing Wear

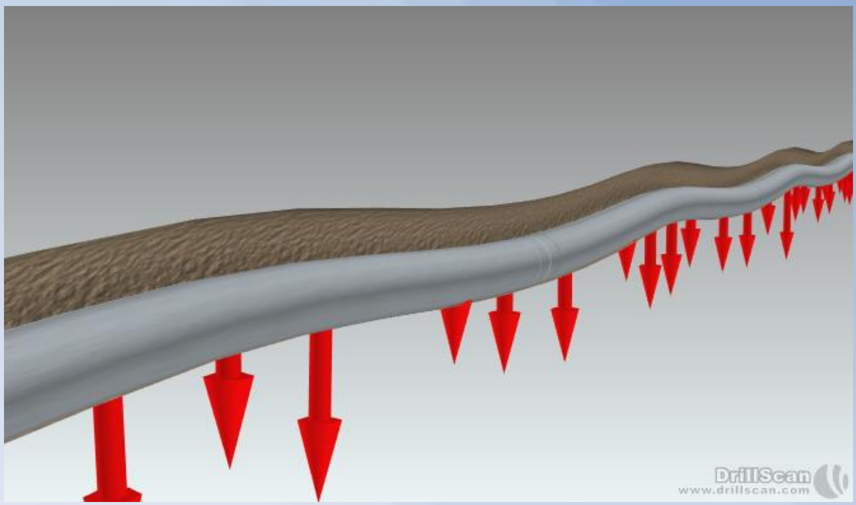
Problem Statement



- **Factors affecting Casing Wear:**
  - **<u>Contact Force</u>**
  - Dog Legs in shallow parts
  - High Tension (higher contact force)
  - ROP (increasing contact time)
  - Operations (Rot. Off Bottom, Back Reaming)
  - Hard Banding (Wear Factor)
  - Mud lubricity
  - Drill Pipe Protectors



Stiff-String



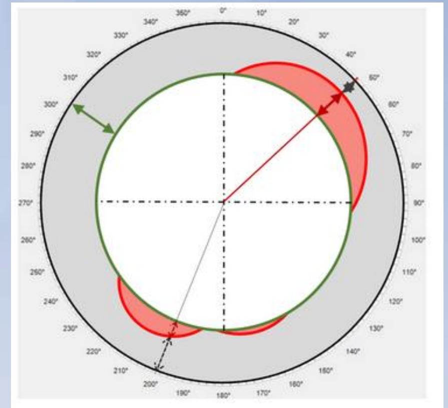
Soft-String

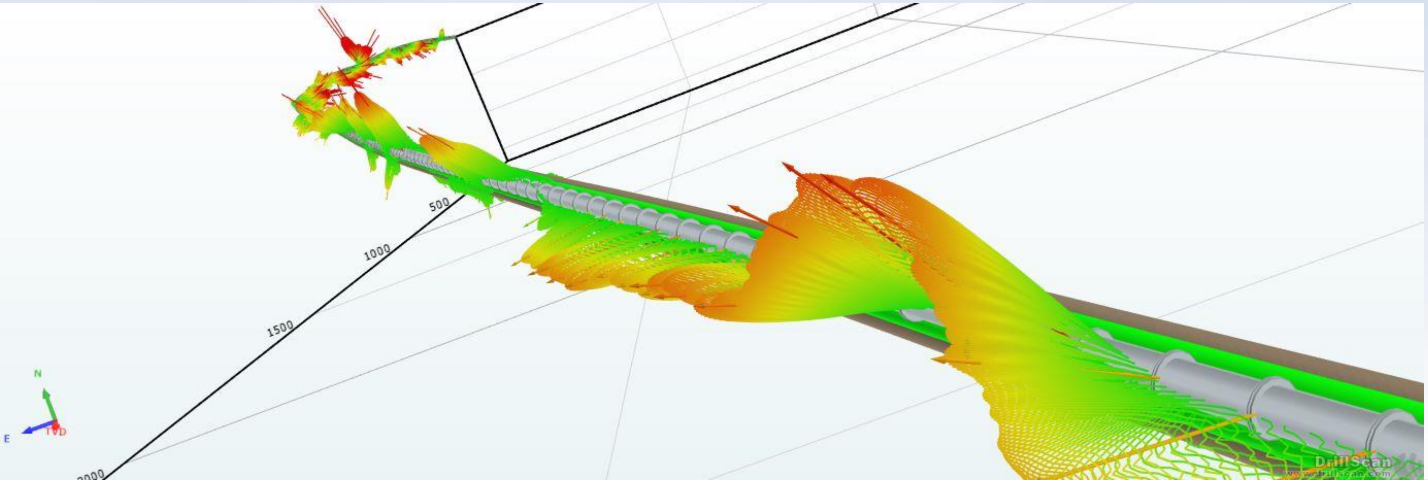
More Accurate Contact Force Calculation with Stiff-String

>> More accurate Casing Wear

New Casing Wear Model

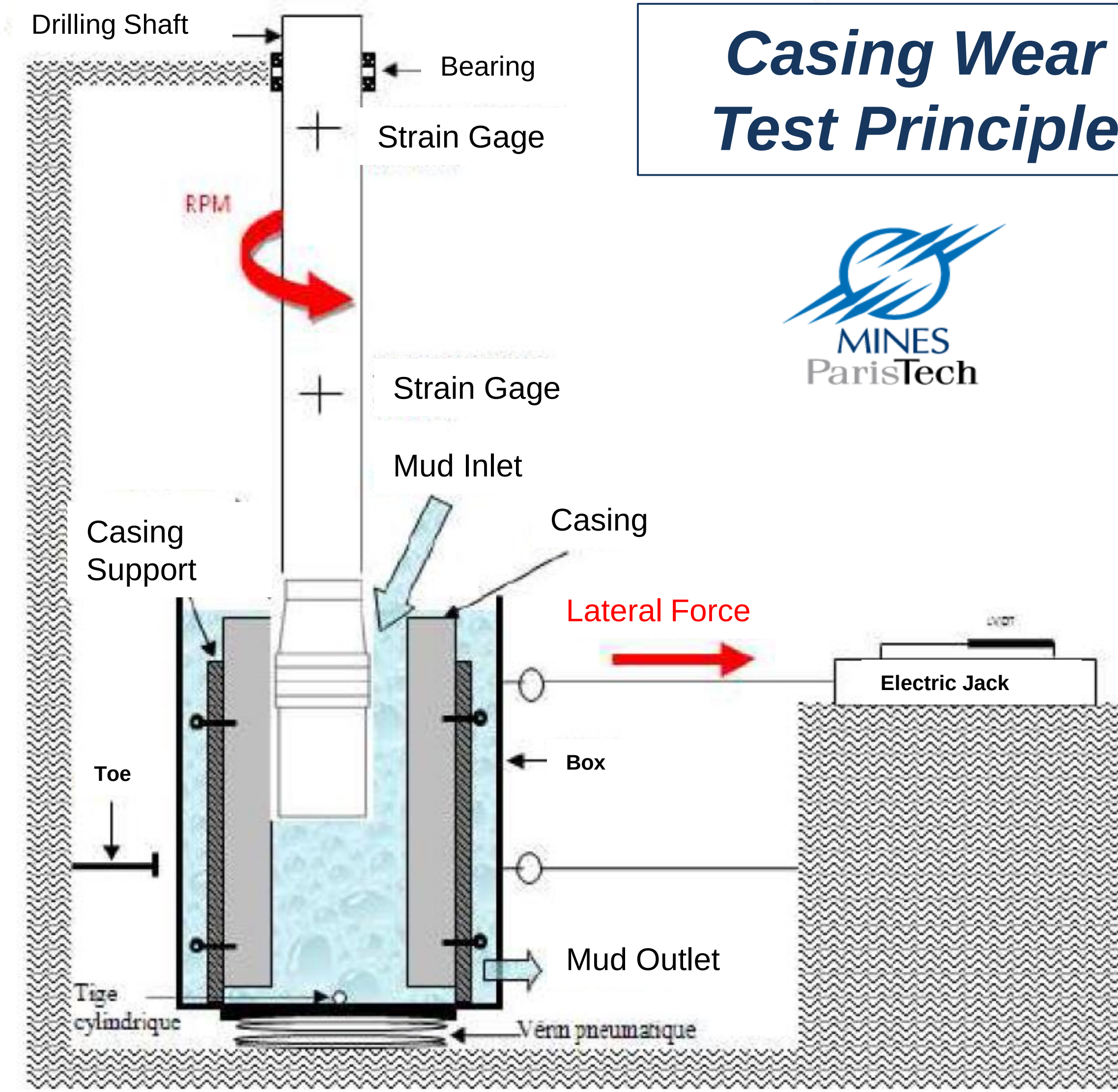
- Stiff-string calculation with Contact Force Calculation
- 3D orientation of Contact Force & Wear
- Accurate Tool-Joint vs Body Contact Force
  - Wear Factor for TJ
  - Wear Factor for Body
- Realistic Dog Leg Effect (even Micro Dog Leg)
- Effect of the range of DP (Range 2 vs Range 3)
- Linear & non-linear Wear model





Casing Wear Test

Casing Wear Test Principle



MINES ParisTech

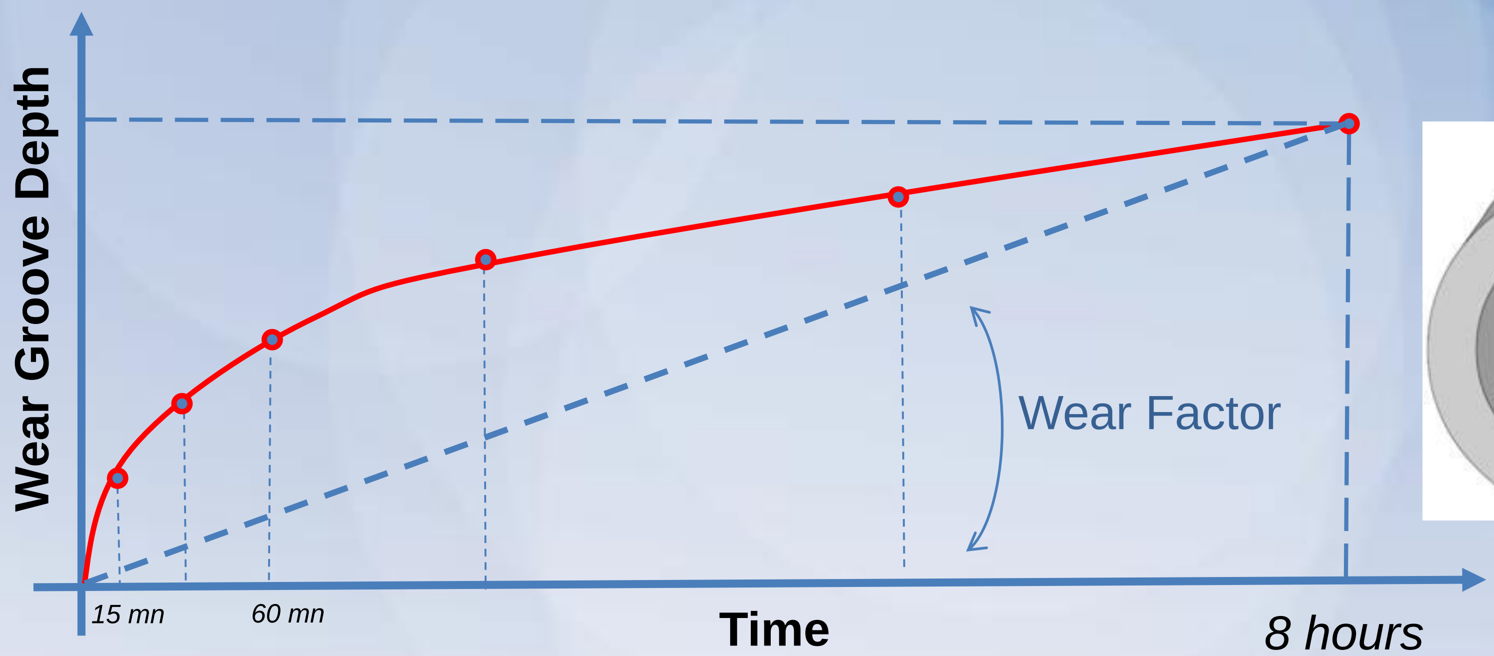
Casing Wear

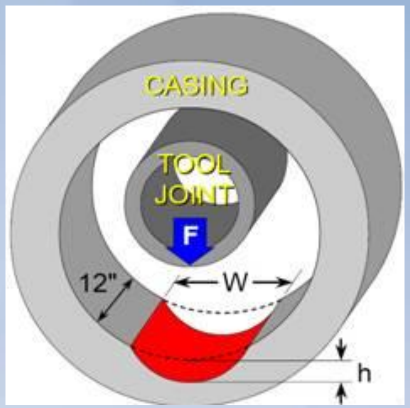
Casing Wear Test

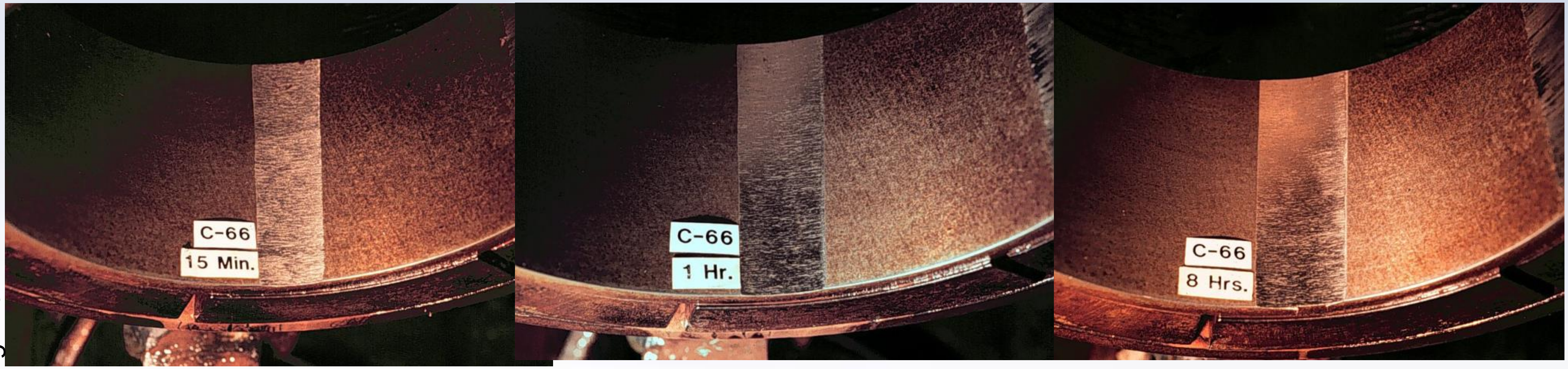
MINES ParisTech

Casing Wear

Casing Wear Test



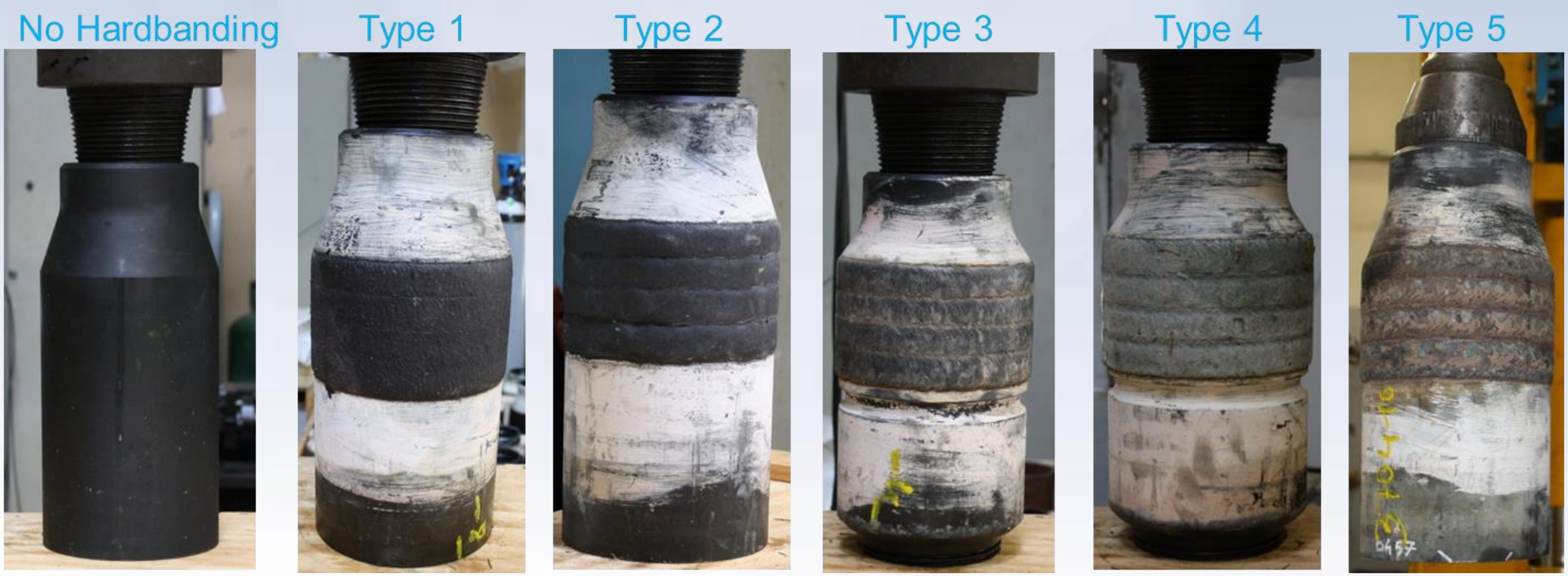




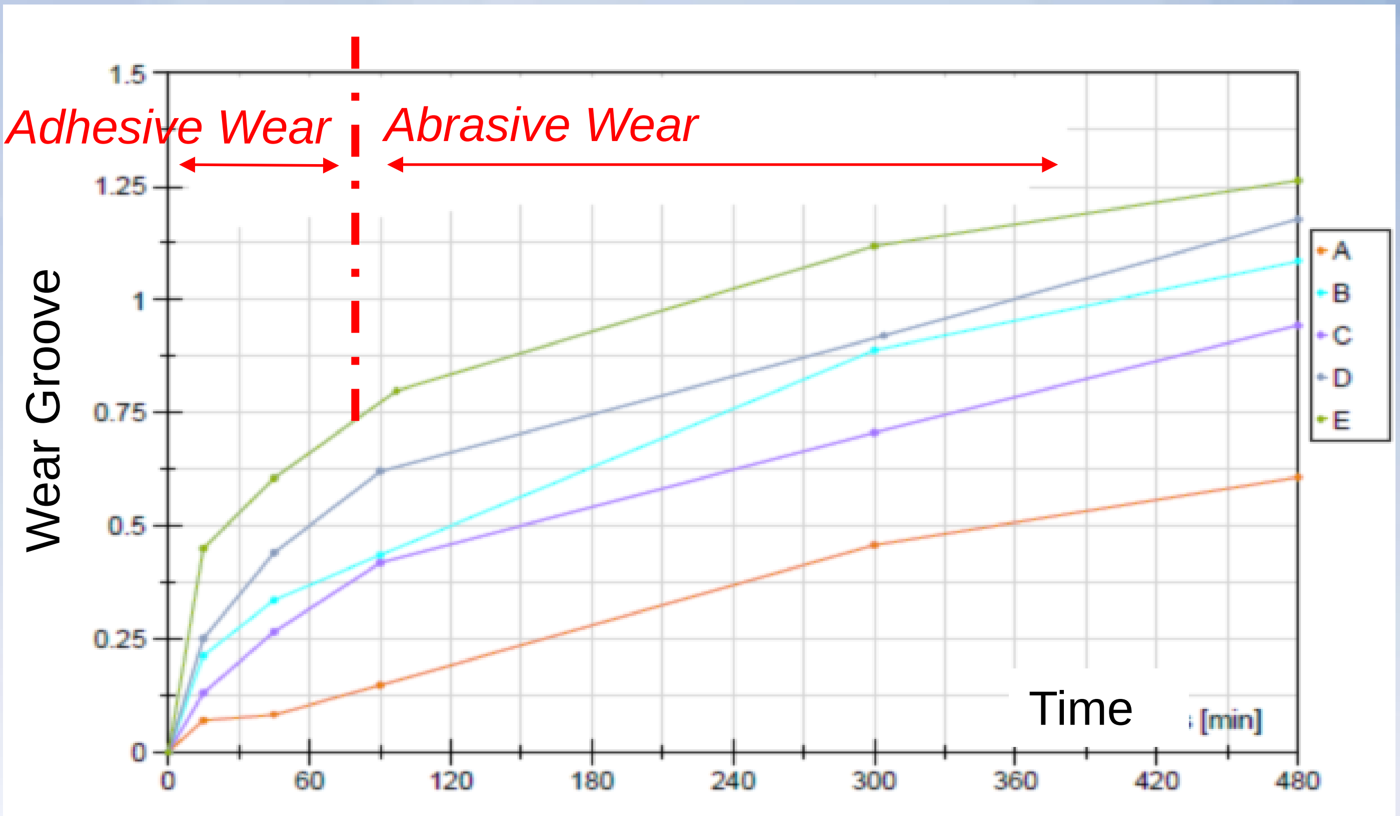
Casing Wear

Casing Wear Test

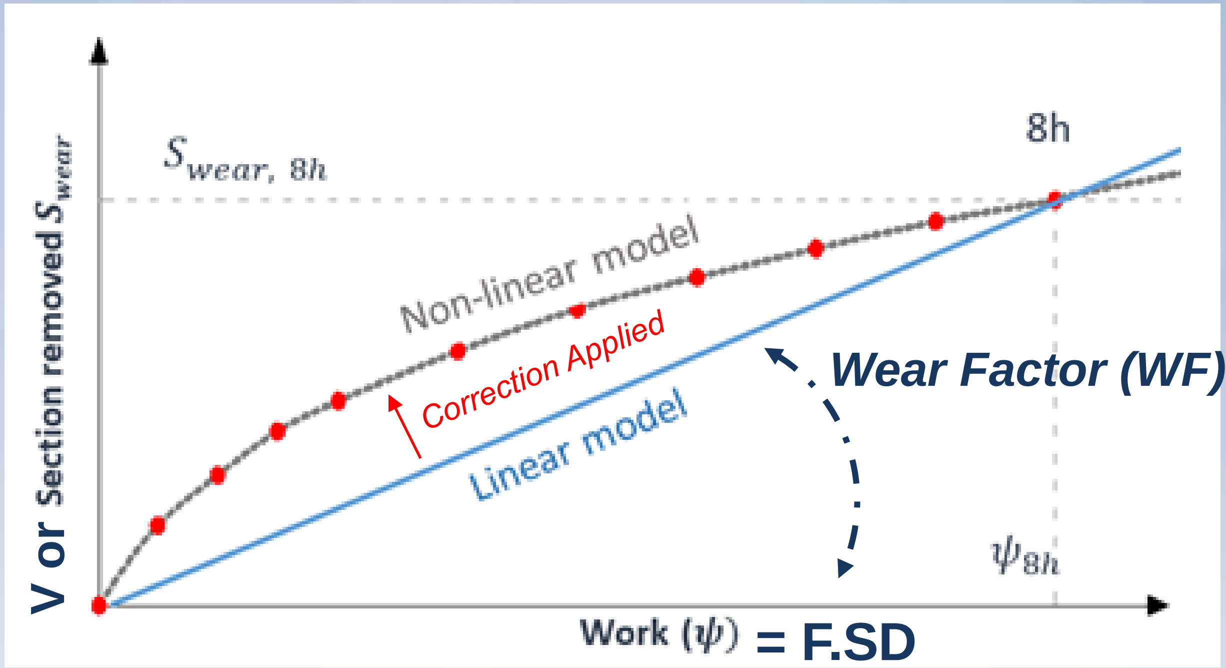
- R&D Project with TOTAL, MINES ParisTech
- Casing Wear Tests in the Lab (API Standard 7 CW)
- Casing grade = L80, T95 & Q125
- 6 types of Hardbanding
- Effect of RPM and Side Force Studied



Example of tests for 5 hard-bandings



- *Non-linearity observed*
- *Significant differences between hard-banding*
- *Slight differences with DEA42 project*



Hall's linear Model (1994)

V = WF . F . SD

V = Volume worn per unit length
F = Contact Force
SD = Sliding Distance = f (ROP, TJ, RPM…)

Empirical Correction Factor applied for Non-Linearity

Conclusion

- **Advanced String/BHA modeling required to:**
  - Optimize BHA to drill smooth wellbore
    - Neutral BHA in the lateral section
    - WOB and Gage length have an effect on BUR
  - Reduce the TVD uncertainty
    - Wellbore Reconstruction
    - Continuous Survey (Measured or Calculated)
  - Better predict completion run in hole operations
    - Torque & Drag & Buckling very sensitive to Dog Legs
    - New Buckling Severity Index to better predict the occurrence of Buckling / Failure (high stress)

Thanks for your attention. Any questions ?