- Deriving Wellbore Quality Metrics from Trajectory Calculations
- Angus Jamieson

50th General Meeting
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Calgary, Canada

Angus Jamieson

- Introduction
  - H&P Technologies UK (AJC team)
  - 40 years DD and Marine Ops
  - Heriot Watt Civil Engineering Bsc 1979 FRICS
  - Based Inverness, UK
  - Specialized in
    - Navigation and Positioning
    - Directional Drilling

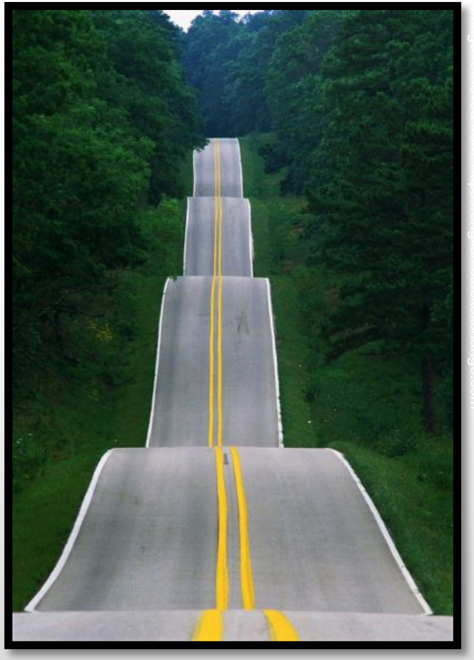
TORTUOSITY Questions

- Does your lateral look like this?
- Does it Matter?
- What about the Surface and Intermediate?
- Why is it important to achieve exceptional steering control?
- Is the best smooth wellbore one that is not steered?
- Should we steer 100% of the lateral or should we focus steering only when needed.

UNDULATING TORTUOSITY

- What is meant by undulations in a Lateral?
- How can you measure it?
- Does it affect production?
- Does it impact drilling?
- Does it affect the cement job and zonal isolation?
- Does this affect the quality of Stimulation
- How about Production? $$$

Vertical Undulation



Lateral Undulation[4]

UNDULATING TORTUOSITY

- Zonal Isolation?

Image Extracted from:
http://www.engineerlive.com/content/22351

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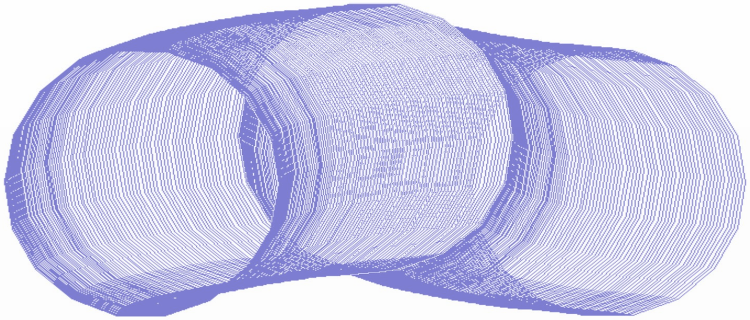
Vertical Undulation

Lateral Undulation

12 Reasons Why Tortuosity is Important ?



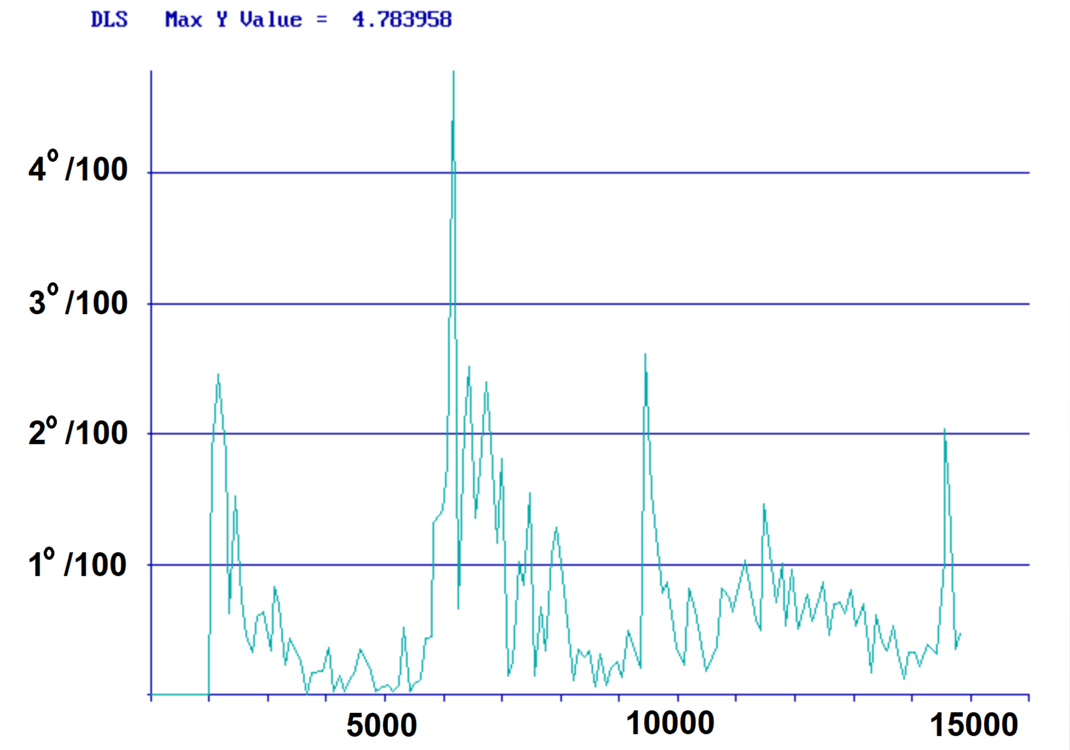
- It increases torque and drag while drilling
- It reduces buckling resistance in drill pipe
- It increases drillstring fatigue when rotating
- It impedes hole cleaning while drilling
- It increases drag when running casing
- It compromises cement job quality
- It causes variations in cross section due to cuttings traps and so..
- It can effect production rate
- It can reduce production quality
- It compromises survey accuracy with the consequence that
- It makes geo-steering more uncertain
- It compromises geological modelling accuracy

Ways to measure tortuosity

DLS against MD

- Easy to calculate
- Uses survey data
- Easy to Understand

- The less you survey the better you look
- May miss key points
- No simple comparison



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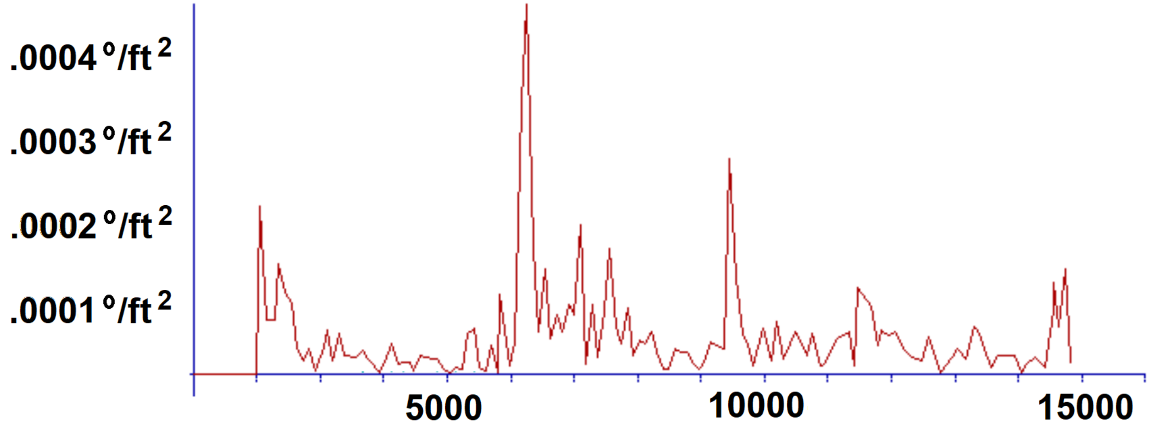
Ways to measure tortuosity

Differentiate the DLS curve
dDLS/dmd

- Measures consistency
- Does not penalise planned Curvature



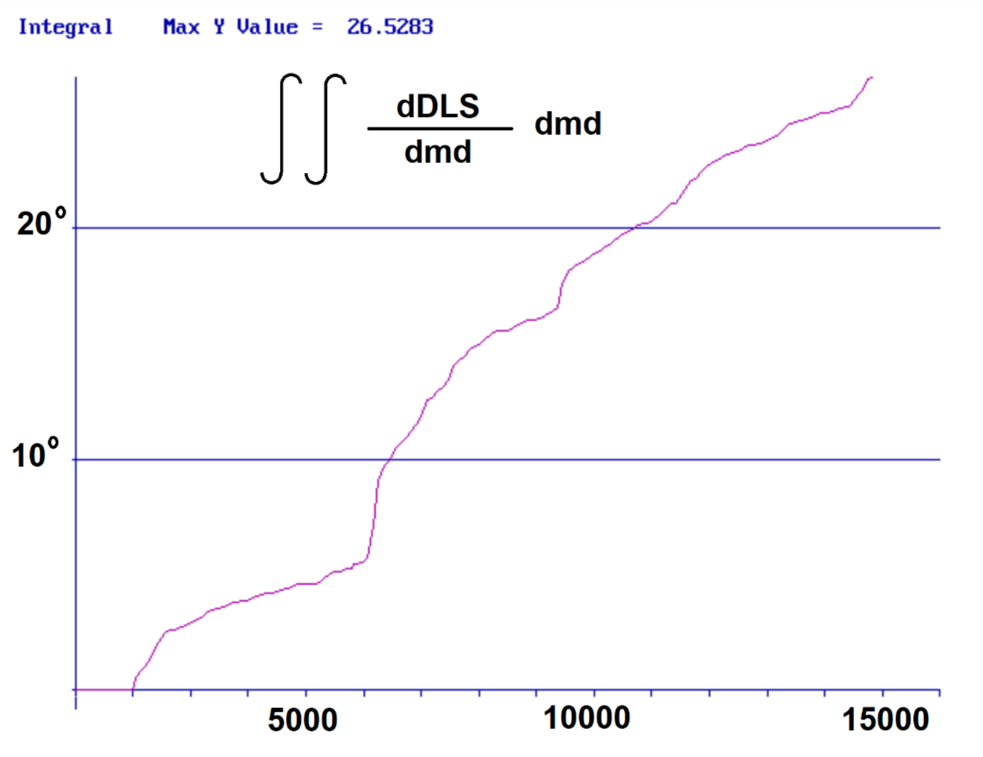
- Only uses pulsed surveys
- May miss key points
- No simple comparison
- Hard to explain

Ways to measure tortuosity

Double Integrate the Differentiation

- Measures consistency
- Does not penalise planned Curvature
- Easy to Calculate in XL
- Easily defined as ‘Unwanted Curvature’

- Only uses pulsed surveys
- May miss key points

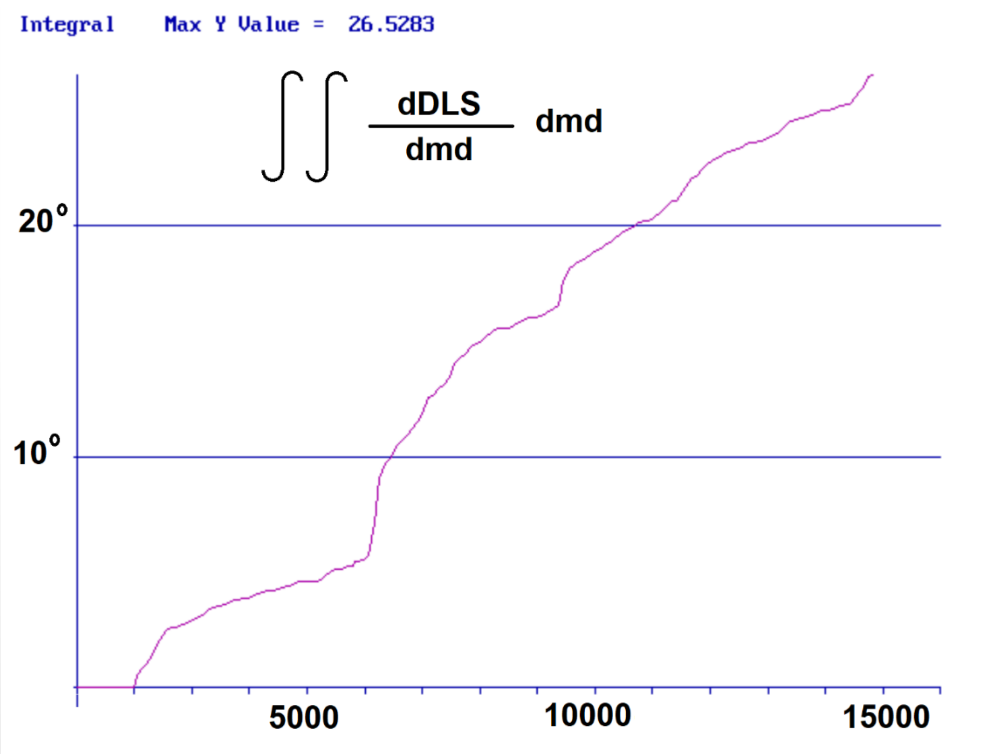


Traditional Tortuosity Index

$$\text{Tortuosity Index} = \frac{\text{Unwanted Curvature}}{\text{Planned Curvature}}$$

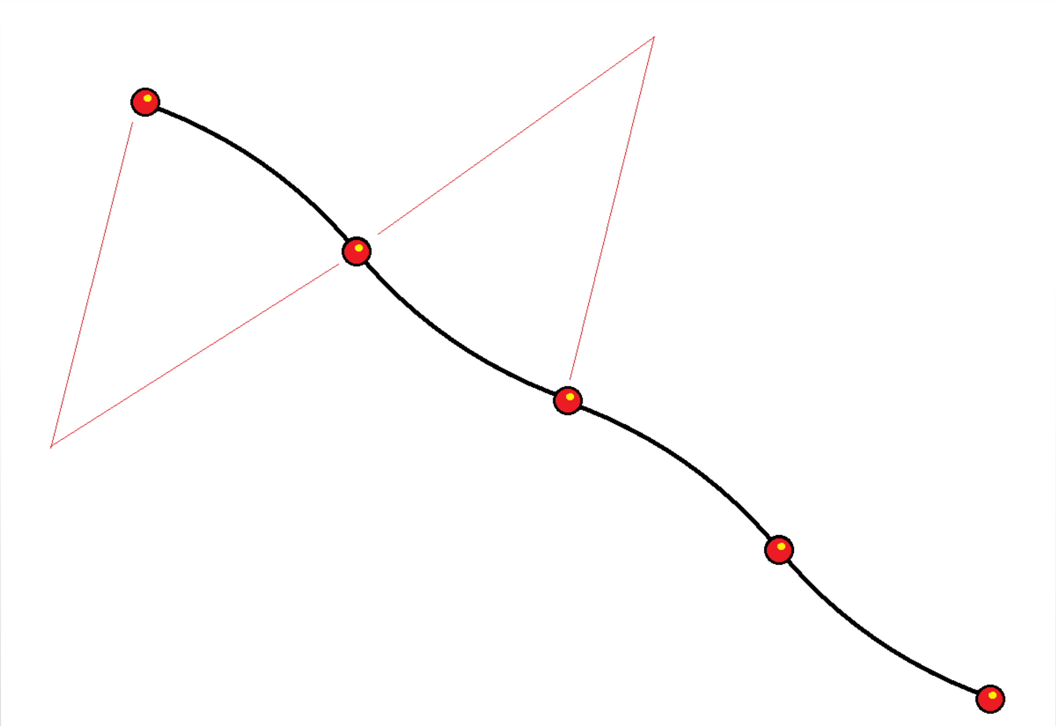
Planned Curvature is not always available

$$\text{TI} = \frac{\text{Unwanted Curvature}}{\text{Total Curvature - Unwanted Curvature}}$$

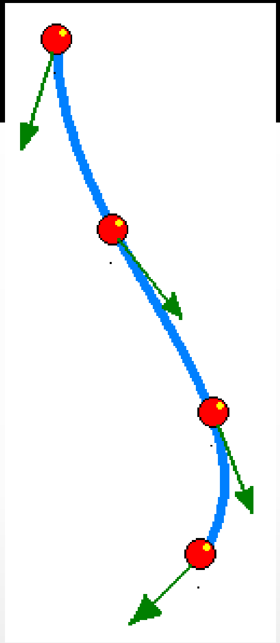


A more revealing approach

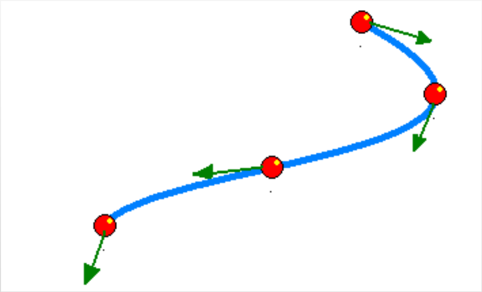
- A BHA designed to give a constant DLS may produce good consistency when 3D arcs are assessed for curvature.
- But what if one survey interval was a drop followed by a build?
- This would assess as consistent DLS from one survey to another
- SO .....
- Assess a Tortuosity index for build consistency and turn consistency separately then combine to a 3D Index



Introducing Effective Turn



- ET = Curve required to change Azimuth
- Easy at low inclinations
- Harder at higher inclinations



- ET = Turn x sin(Inclination)

Toolface and Dogleg Calculations

$$\text{Toolface} = \tan^{-1}\left(\frac{\text{Effective Turn}}{\text{Build}}\right)$$

$$\text{Dogleg} = \sqrt{\left(ET^2 + \text{Build}^2\right)}$$

Toolface by Graphics

- Example

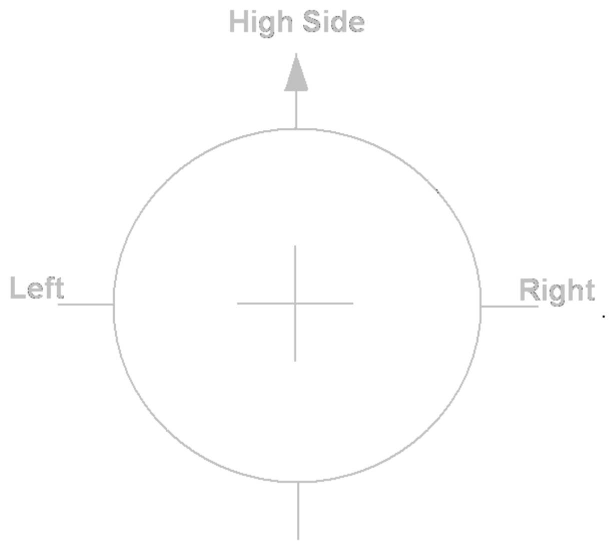
Current Attitude Inclination 25 Azimuth 100

Desired Attitude Inclination 35 Azimuth 124

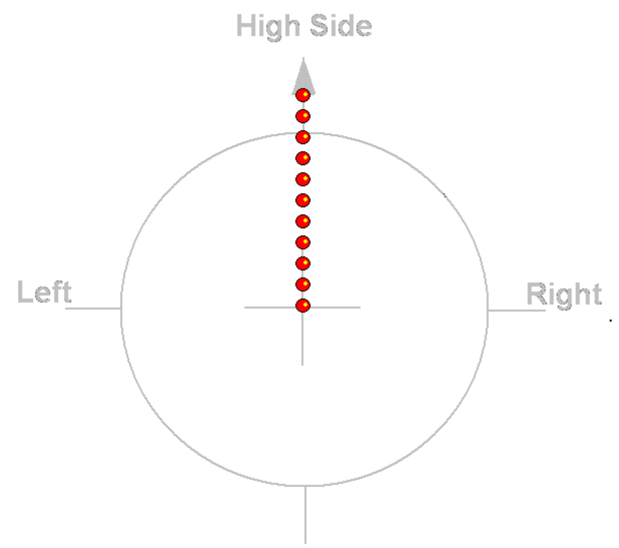
i.e. Build 10 and Turn 24

Effective Turn = 24 sin (30) = 12

Build 10



Build 10



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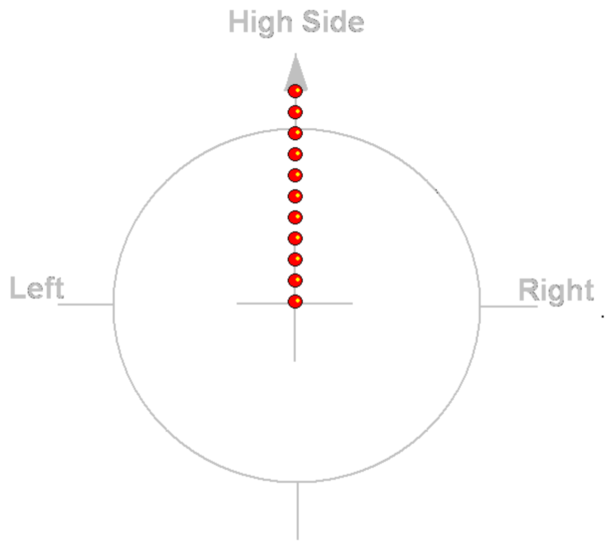
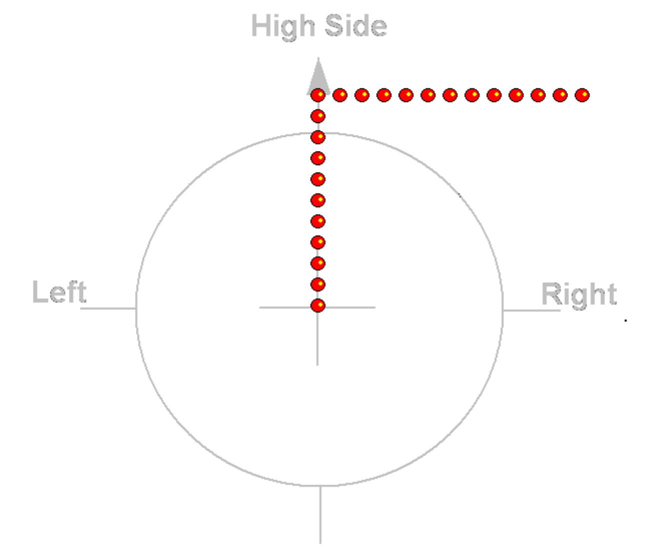
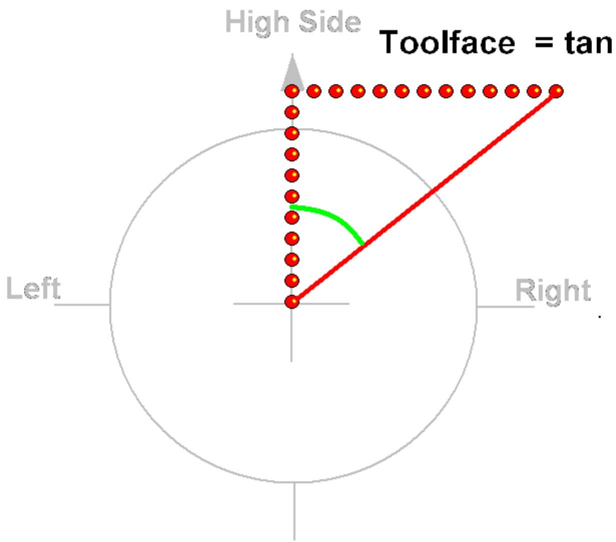
Add ET 12 to the Right



Add ET 12 to the right

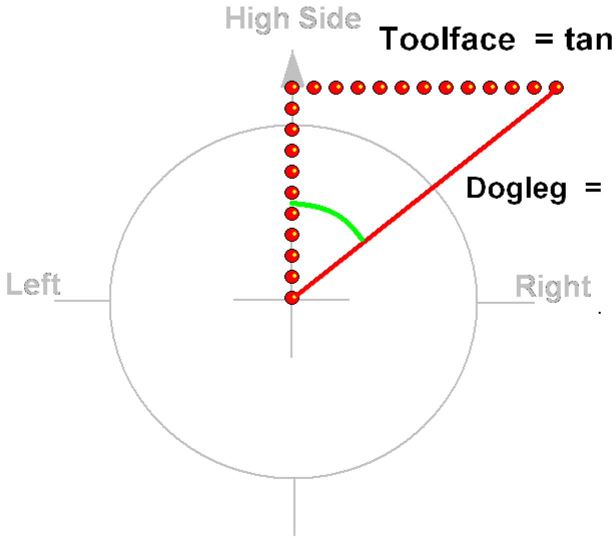


Toolface is the Angle Subtended



$$\text{Toolface} = \tan^{-1}\left(\frac{\text{Effective Turn}}{\text{Build}}\right)$$

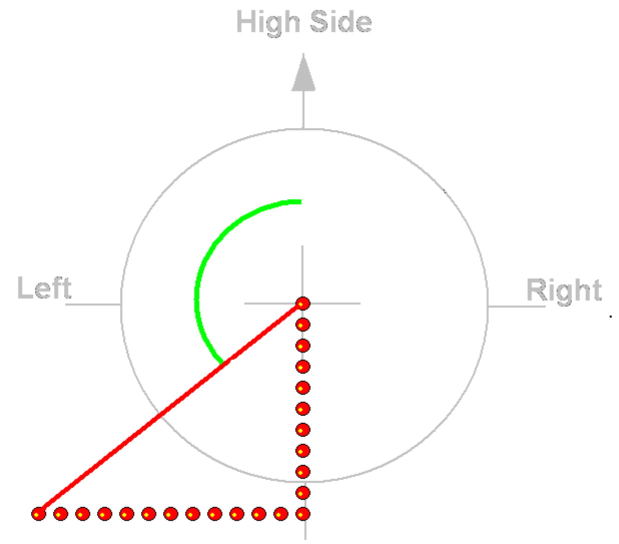
Dogleg = Length of Slope



$$\text{Toolface} = \tan^{-1}\left(\frac{\text{Effective Turn}}{\text{Build}}\right)$$

$$\text{Dogleg} = \sqrt{\left(ET^{2} + \text{Build}^{2}\right)}$$

Drop with Left Turn



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Calculating High Side and Lateral Tortuosity

- Calculate Build Rate and Turn Rate for each interval
- Convert Turn Rate to Lateral DLS (Effective Turn Rate)
  - ETR = Turn * sin (inclination)
    - (Use average inclination for interval)
- Calculate δBR and δETR from one interval to next (as absolute values)
- Total Build = Σ BR x δMd   Unwanted build = Σ .5 x δBR x δMd
- Total ET = Σ ETR x δMd   Unwanted ET = Σ .5 x δETR x δMd
- High Side Tort Index = Unwanted Build / (Total Build – Unwanted Build)
- Lateral Tort Index = Unwanted ET / (Total ET – Unwanted ET)

Calculating High Side and Lateral Tortuosity

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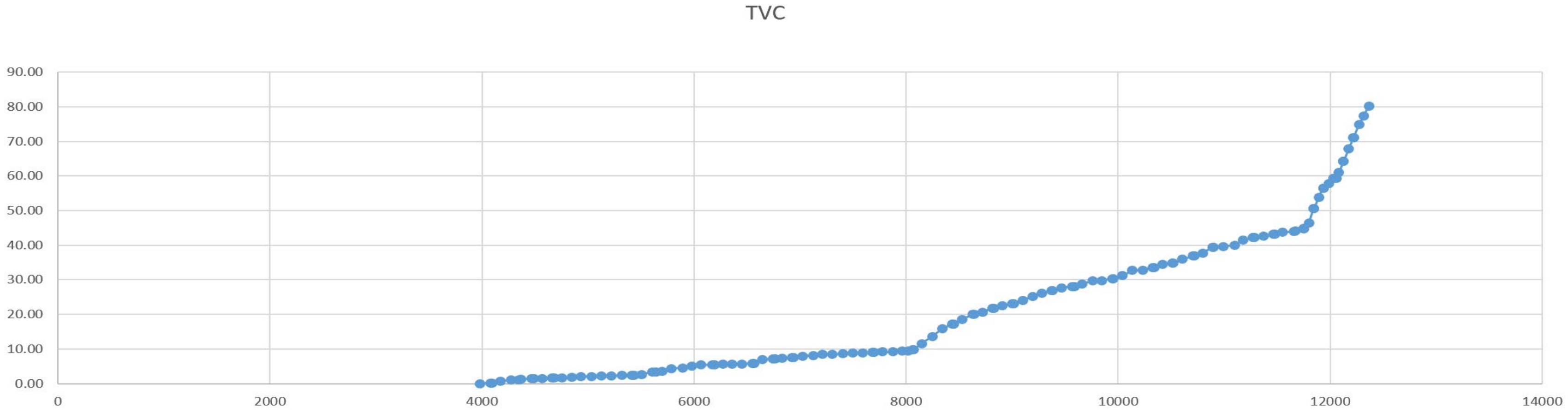
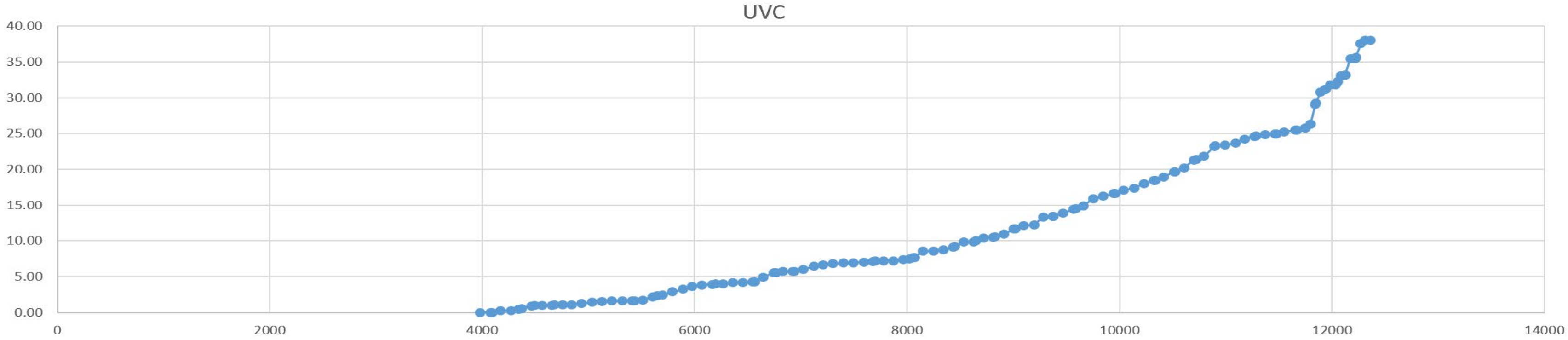
- High Side Tort Index = Unwanted Build / (Total Build – Unwanted Build)
- Lateral Tort Index = Unwanted ET / (Total ET – Unwanted ET)

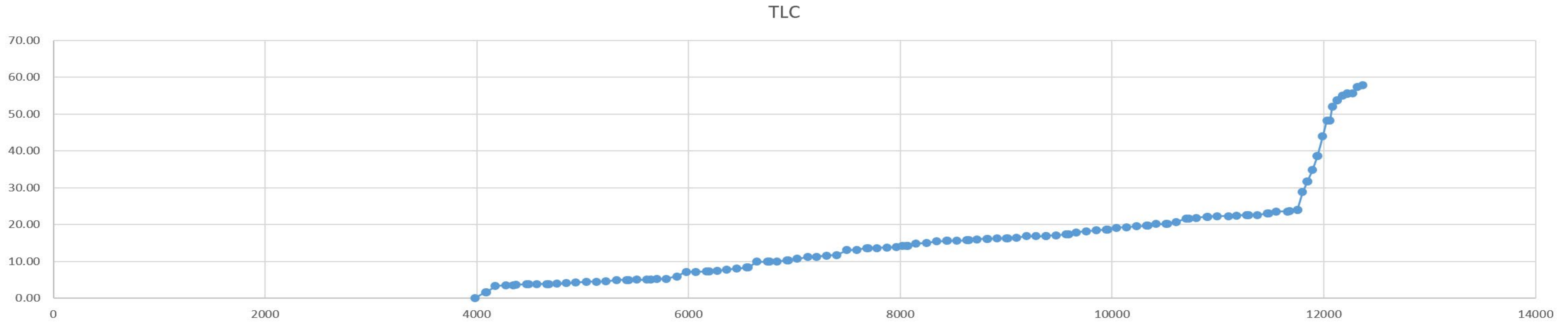
$$\textbf{Combined 3D Tortuosity Index} = \sqrt{(\text{Highside TI})^2 + (\text{Lateral TI})^2}$$

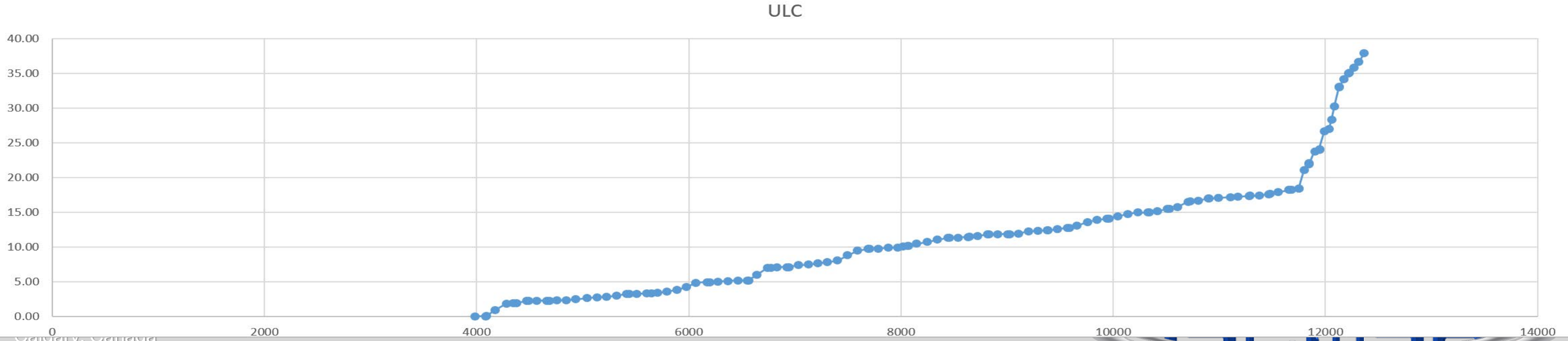
Vertical Curvature (normal offshore well) VTI = 0.9



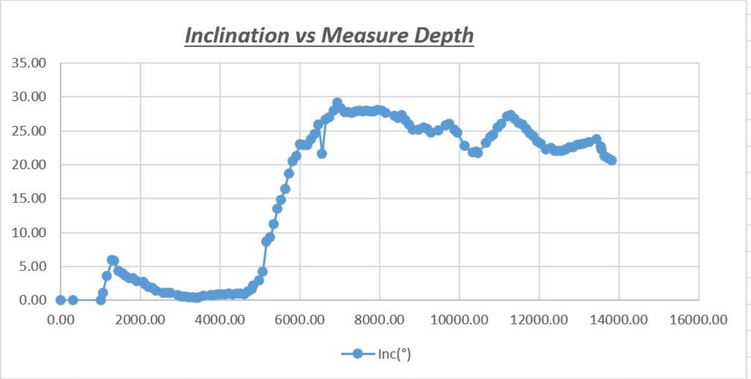


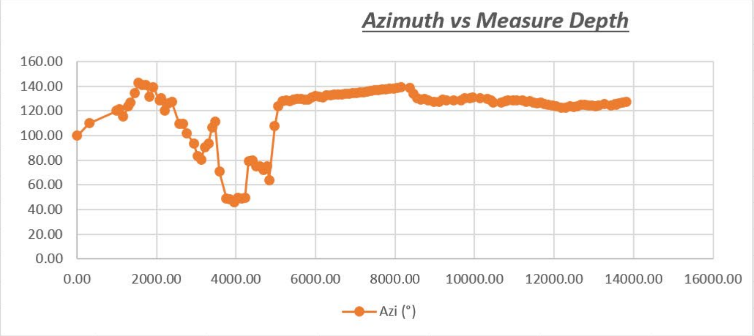
Lateral Curvature LTI = 1.91 3D TI = 2.11

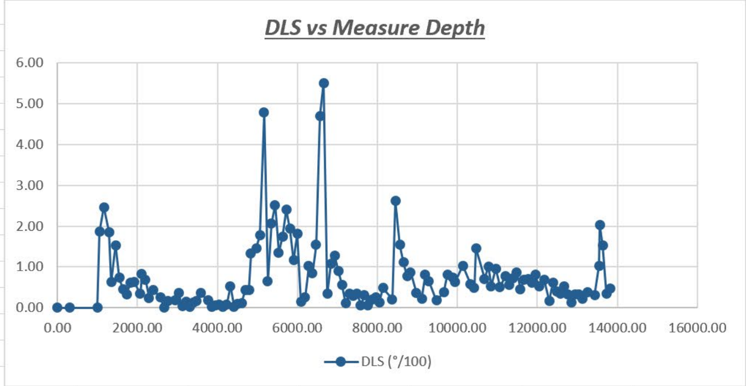


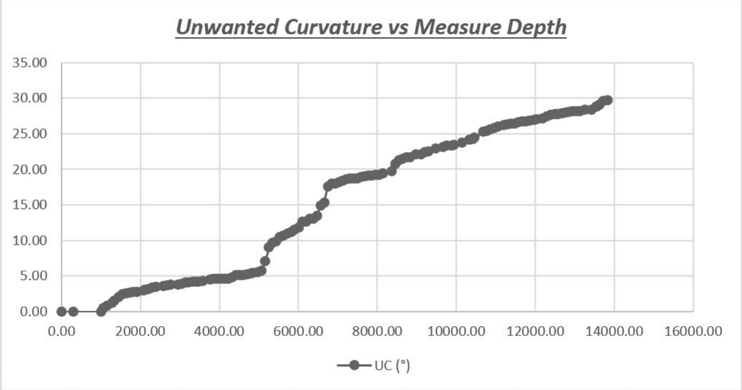


Traditional TI based on DLS alone = .45 (looks OK?)

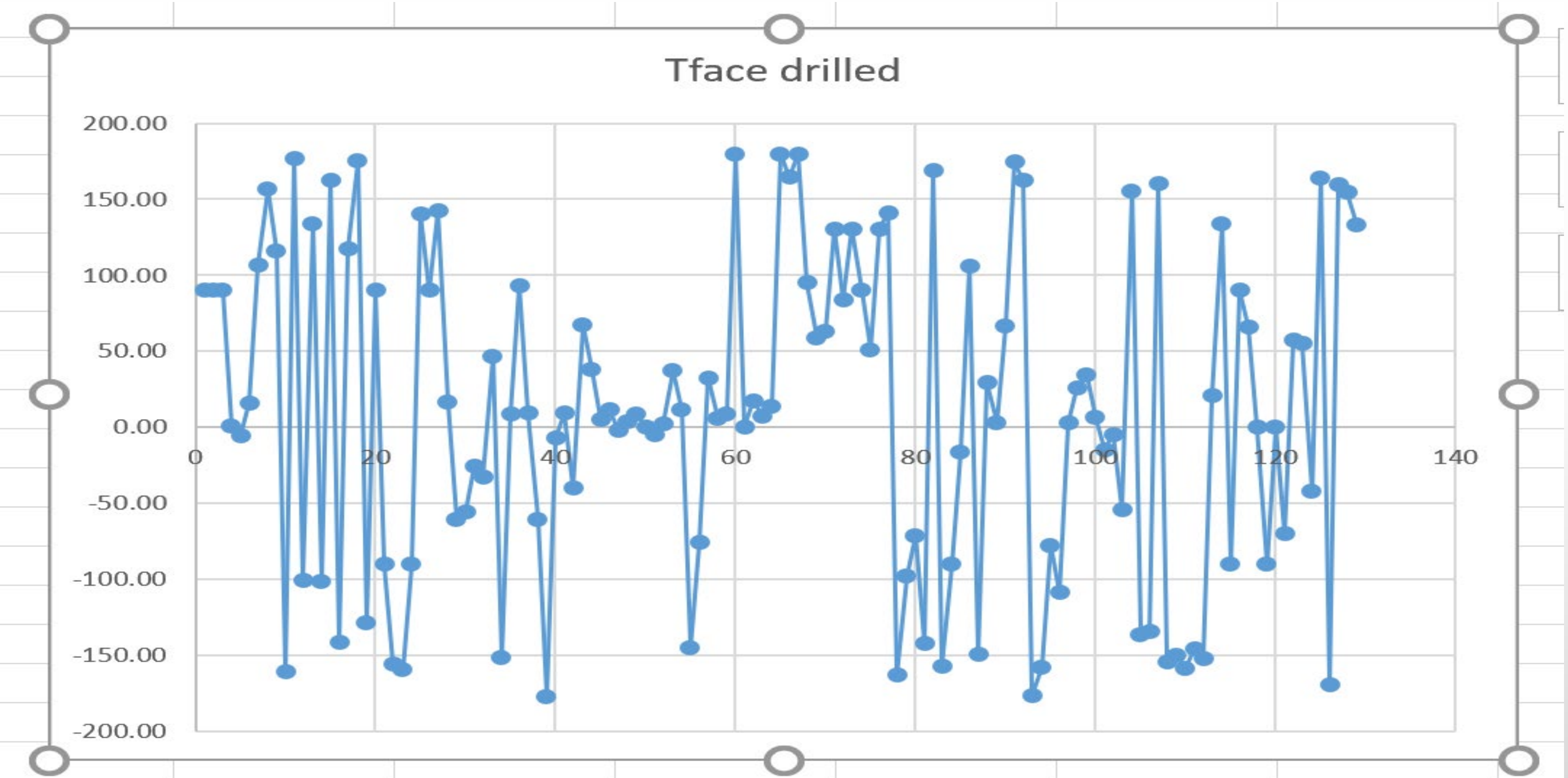








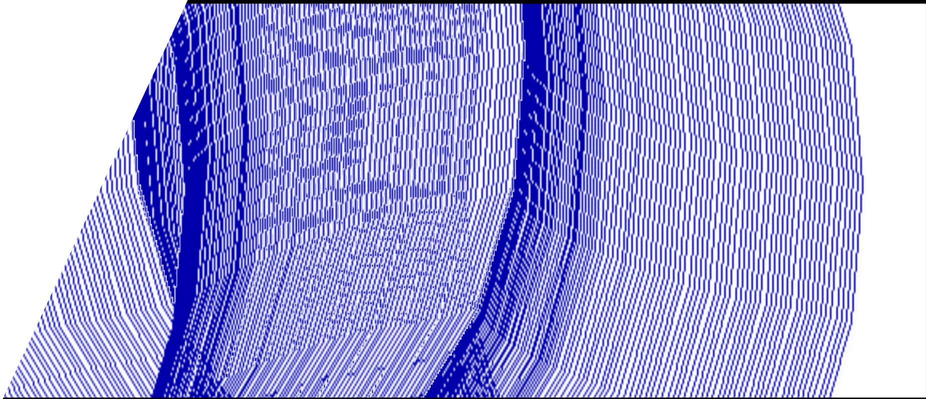
This well had a vertical TI of 1.00 and Lateral TI of 2.23 ! Combined 3d TI of 2.44 ! The driller could not hold Toolface

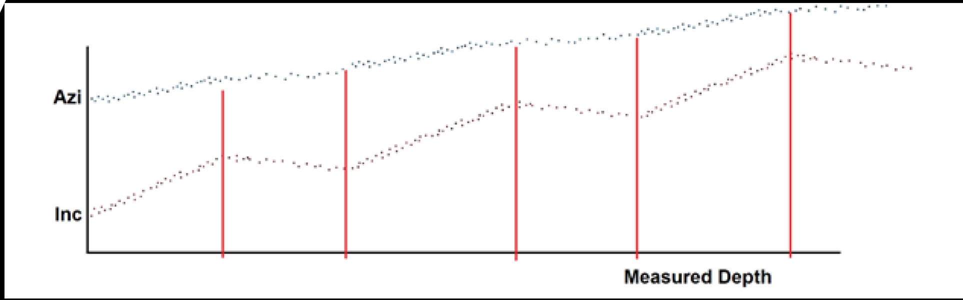


Measuring High Resolution Tortuosity

- **Uses all available data**
- **Assesses true motor yield functions**
- **Models a true trajectory in 3D**
- **Does not miss key points**
- **Informs T&D and Hydraulics calcs**

- **Trains DDs or Automation to minimise tortuosity**
- **Allows proper assessment of impact at two thresholds**

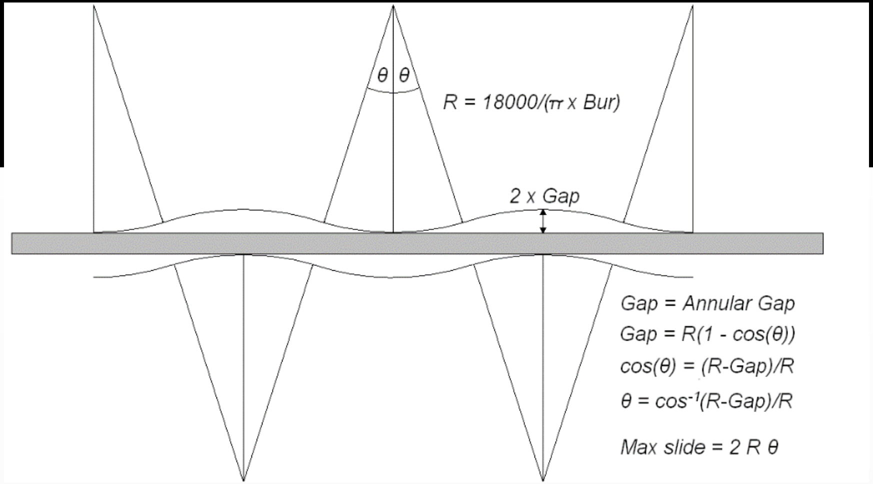




Tortuosity Thresholds

- 1. Stressing Casing

- 2. Stressing Pipe



DLS °/100	13 3/8" 17 1/4	9.5/8" 12 1/4	7" 8.5
1	89 ft	71 ft	54 ft
2	63 ft	50 ft	38 ft
3	51 ft	41 ft	31 ft
4	44 ft	35 ft	27 ft
5	40 ft	32 ft	24 ft
6	36 ft	29 ft	22 ft
7	34 ft	27 ft	20 ft
8	31 ft	25 ft	19 ft
9	30 ft	24 ft	18 ft
10	28 ft	22 ft	17 ft
11	27 ft	21 ft	16 ft
12	26 ft	20 ft	15 ft
13	25 ft	20 ft	15 ft
14	24 ft	19 ft	14 ft
15	23 ft	18 ft	14 ft
16	22 ft	18 ft	13 ft
17	22 ft	17 ft	13 ft
18	21 ft	17 ft	13 ft
19	20 ft	16 ft	12 ft
20	20 ft	16 ft	12 ft

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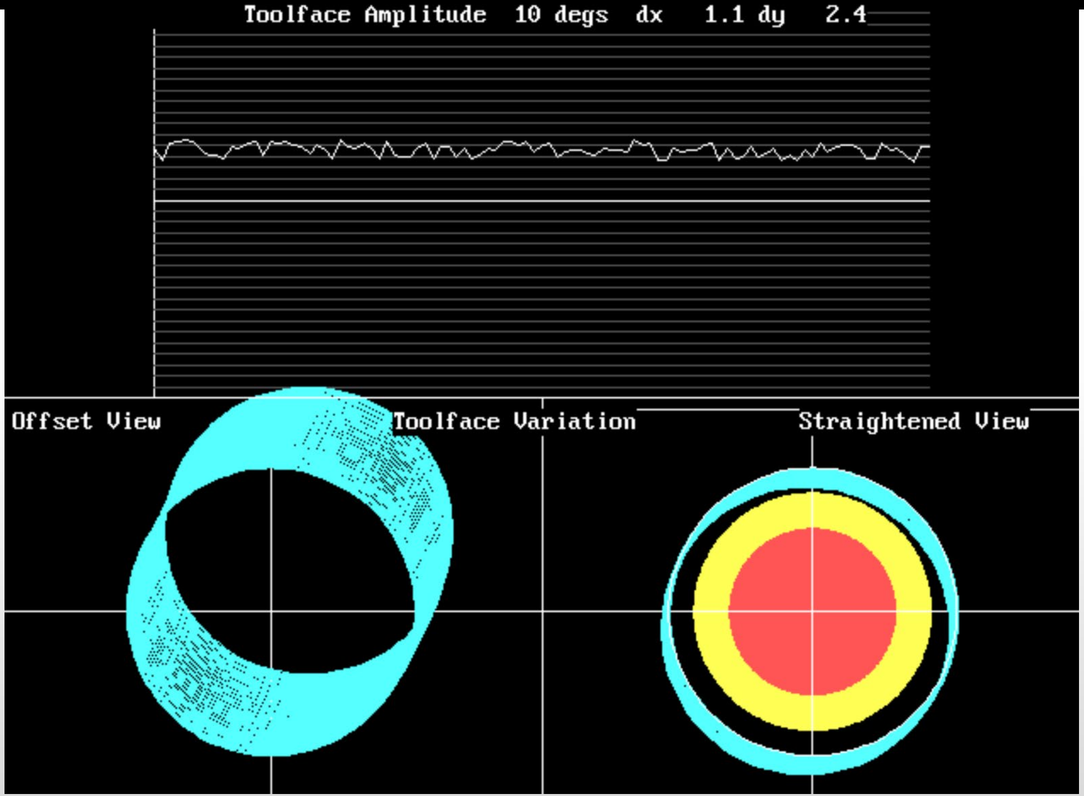
Two thresholds of acceptable tortuosity

The amber area warns
'Encroaches on casing'

The Red area warns
'Encroaches on drillpipe'

This can be measured by
modelling a tubular set
in the wellbore and
reporting stresses necessary
to constrain within the hole.



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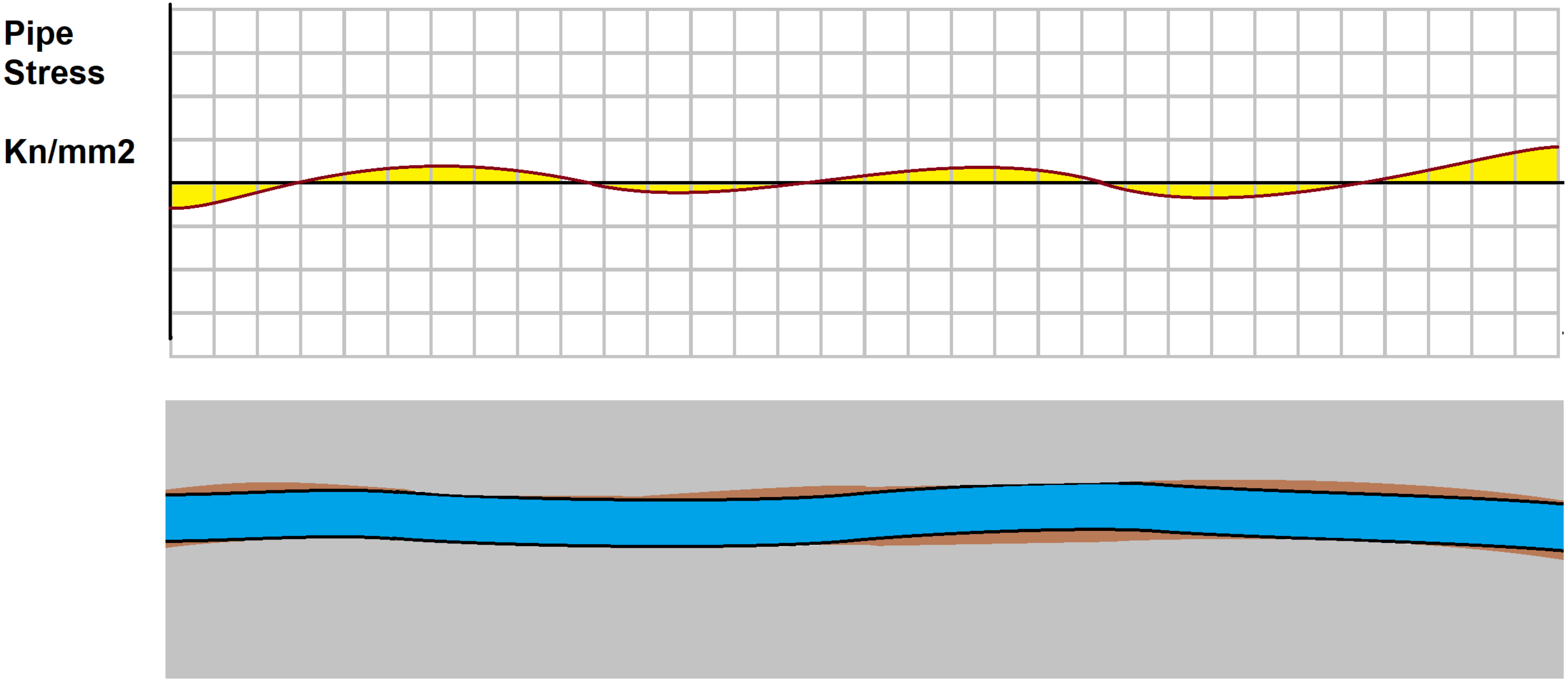
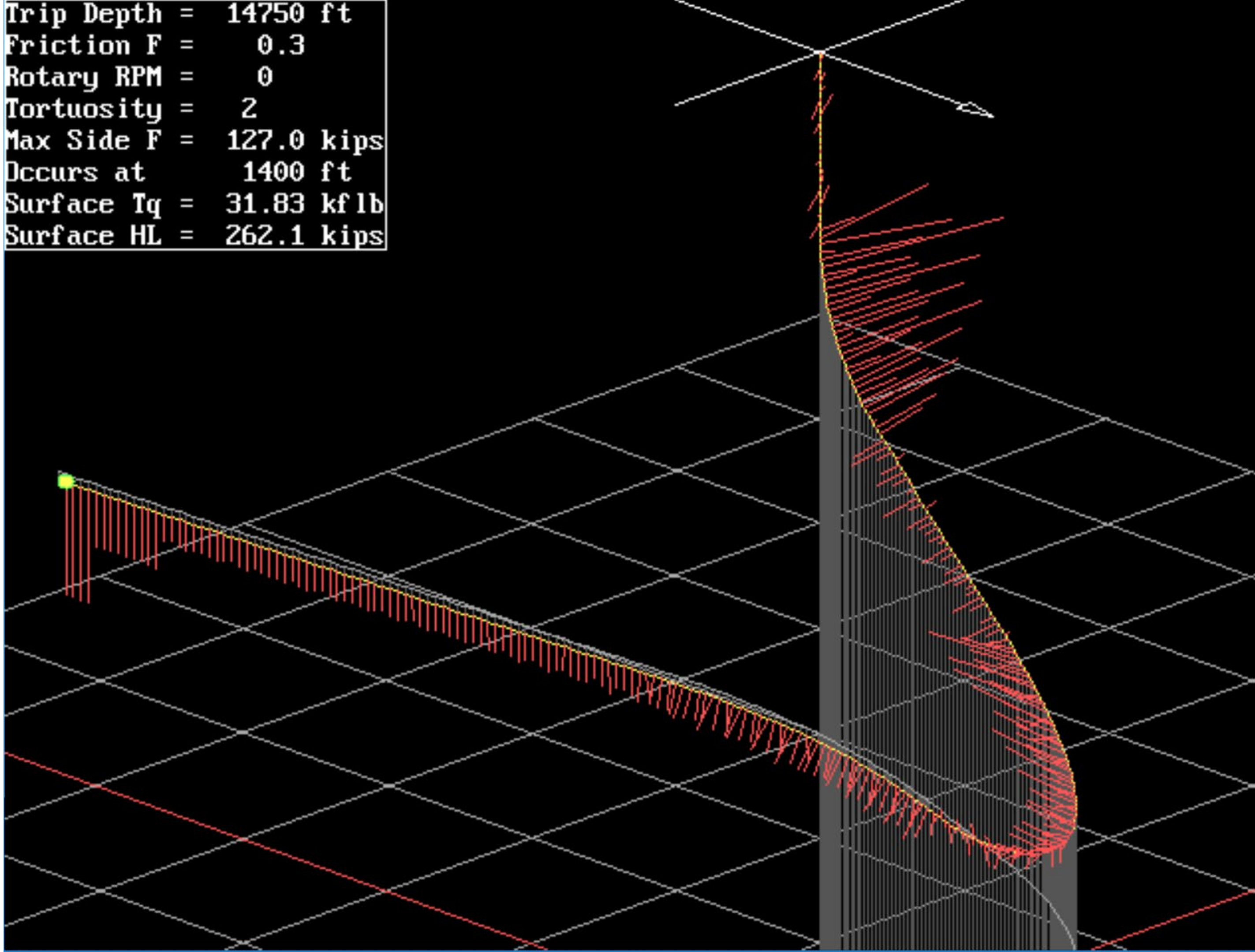

Pipe
Stress
Kn/mm2

Drag Side Forces Modelled correctly



Loch Ness Test Trajectory

- Inverness, Scotland
- Loch is over 900 ft deep with very steep sides – good analog for a well trajectory
- 1250 ft 8 inch PVC Pipe
- Stable and magnetically clean
- Tortuous Seabed Profile
- Nearby glens for hiking include
  - Glen Livet, Glen Morangie
  - Glen Spey, Glen Fiddich

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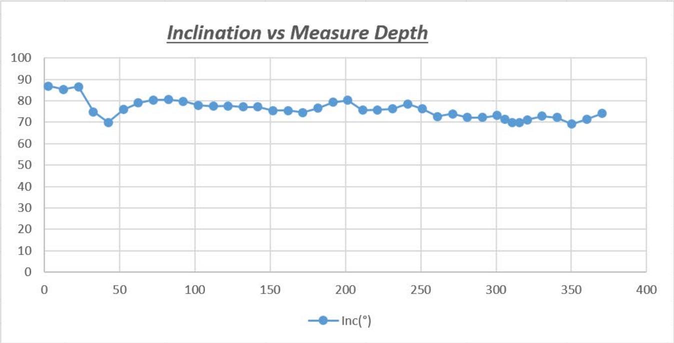
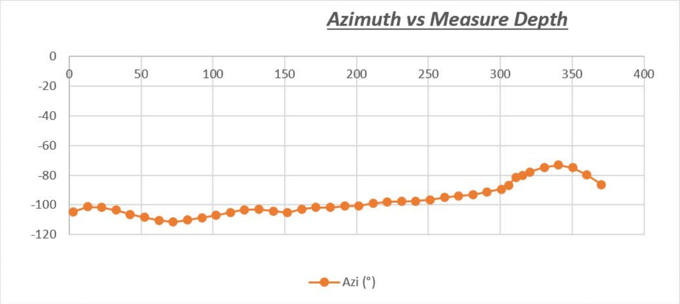
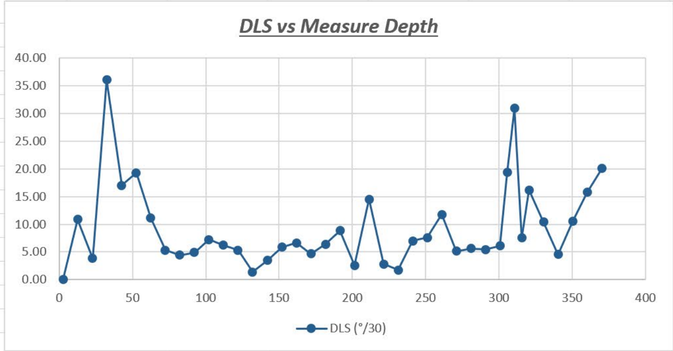
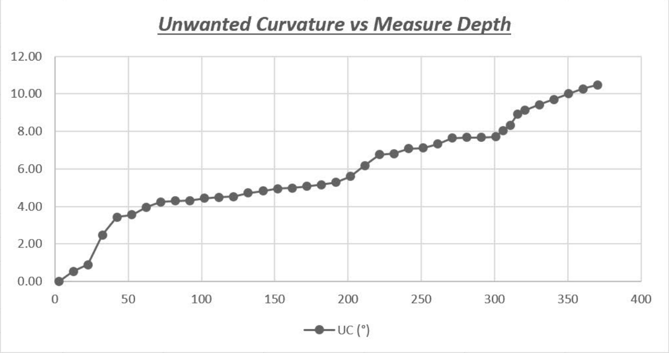
Vertical TI 1.77, Lateral 0.46 & 3D 1.83










Questions ?