Borehole Drift – Effect of Continuous Survey on Wellbore Curvature & Torsion

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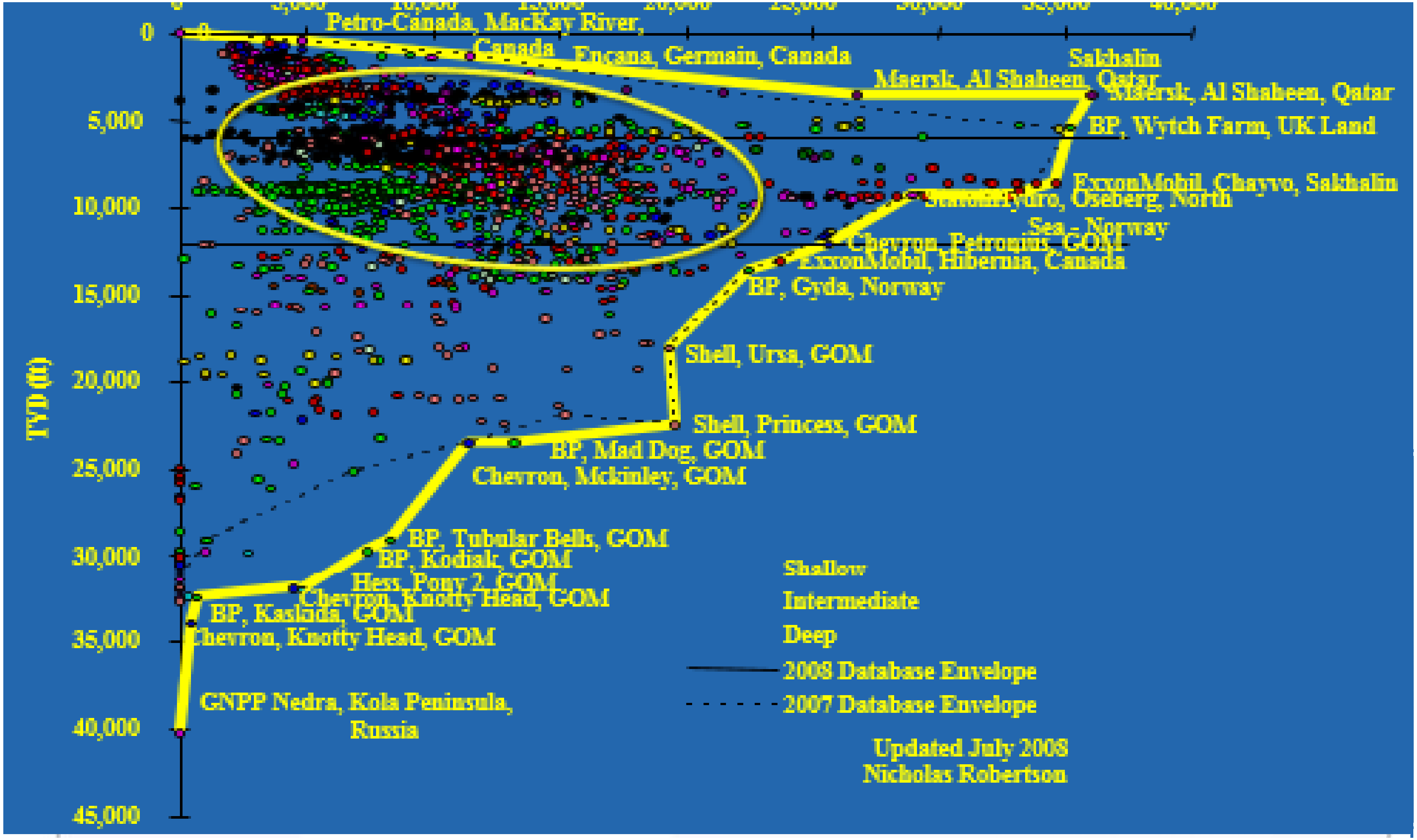
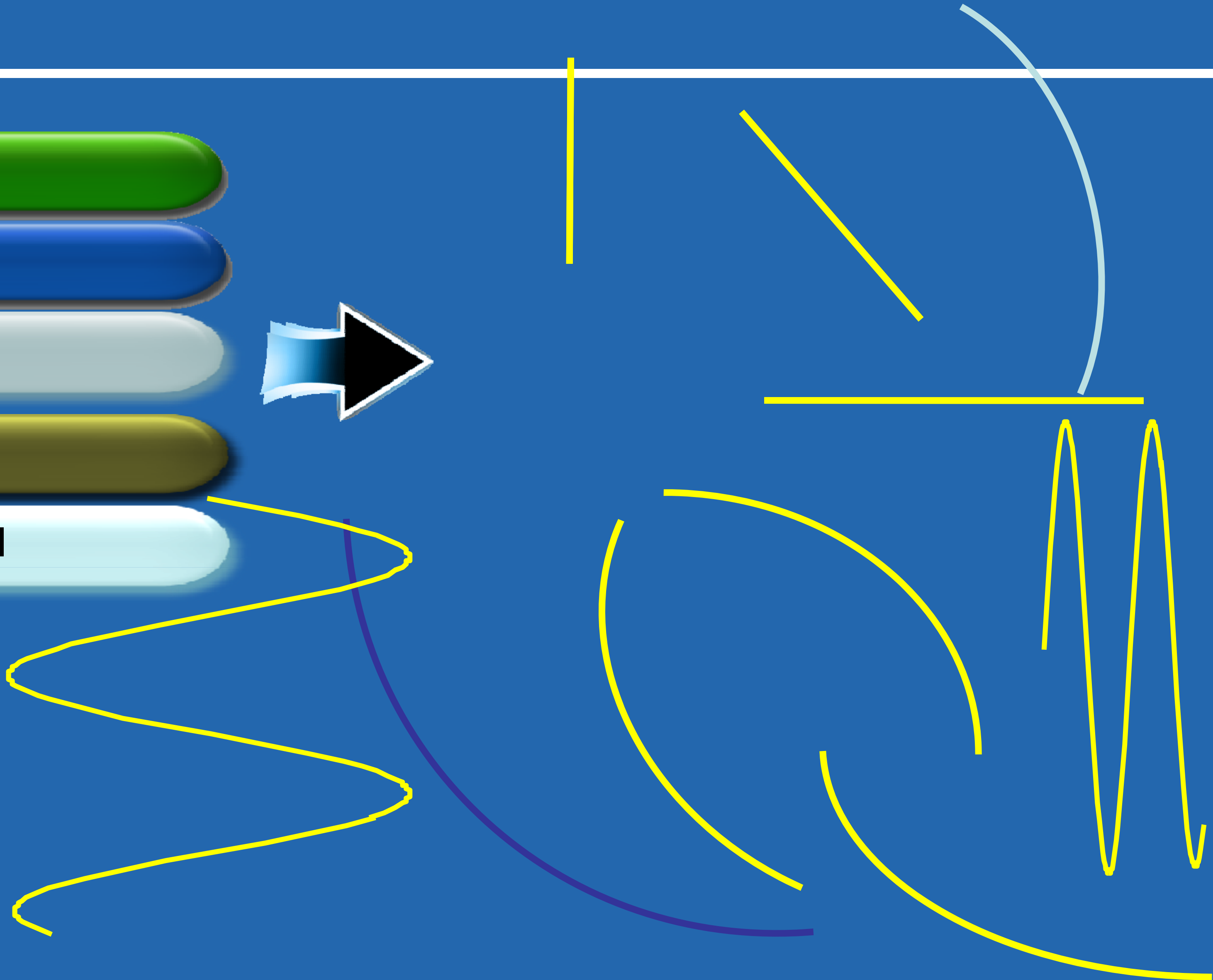
Stretching the Space



Conventional Wellpath Designs

- Type 1
- Type 2
- Type 3
- Catenary
- Horizontal



Are the Design Parameters Enough?

- Is the borehole shape same between all the survey intervals ?
- What is the predetermined borehole shape used ?
- What is the minimum distance of the survey interval to determine the shape?
- What are the assumptions used ?

What is the borehole shape?

- Radius of Curvature Method
- Minimum Curvature Method

√ Assume predetermined shape

√ Different results

√ Wellpath discontinuous

Design Parameters

Tortuosity

Drilling Indices

Torsion

Wellbore Tortuosity

- NATURAL & ARTIFICIAL TORTUOSITY
    - Sine wave method
    - Helical method
    - Random inclination and azimuth method
    - Random inclination dependent azimuth method

Wellbore Tortuosity

- √ **Sine Wave Tortuosity**

  Easy to use

$$\Delta\alpha = \sin\left(\frac{D_n}{P}\times 2\pi\right)\times M \quad \frac{2}{n}(n=1,2,3..)$$

- √ **Absolute Tortuosity**

  Easy to quantify

$$\Gamma_{(abs)_n} = \left(\frac{\sum_{i=1}^{n}\alpha_{adj}}{D_n + \Delta D_n}\right)$$

Design Parameters

Tortuosity

Drilling Indices

Torsion

Drilling Difficulty Indices

Drilling Difficulty Index

$$DDI = \log\left(\frac{D \times H \times T}{S}\right)$$

Mechanical Risk Index

Modified Mechanical Risk Index

$$TRI = \log\left(TDI + R_{cl} + R_{tq} + R_{d} + R_{bu}\right)$$

Trajectory Risk Index

Wellbore Score Card

Tortuosity Index

- Qualitative Prediction
- Subjective
- Weighting factors needed

Design Parameters

Tortuosity

Drilling Indices

Torsion

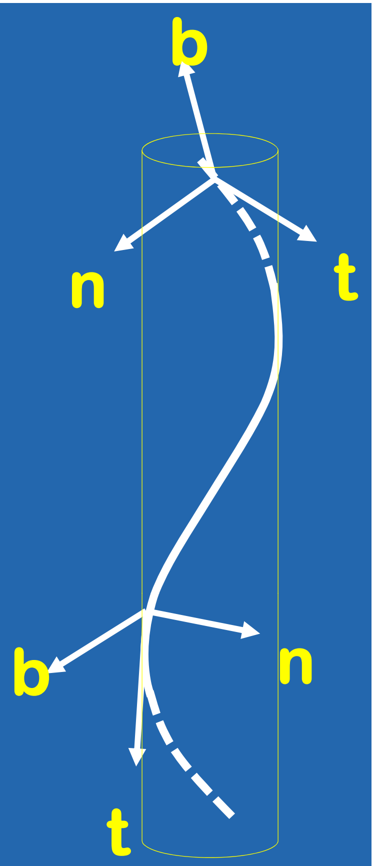
Wellbore Curvature & Torsion

- √ • What is Wellbore Curvature

Curvature is the bend of the wellpath

- √ • What is Wellbore Torsion

Torsion measures the departure of the wellpath from a plane, or how sharply wellpath turns



Curvature is discontinuous

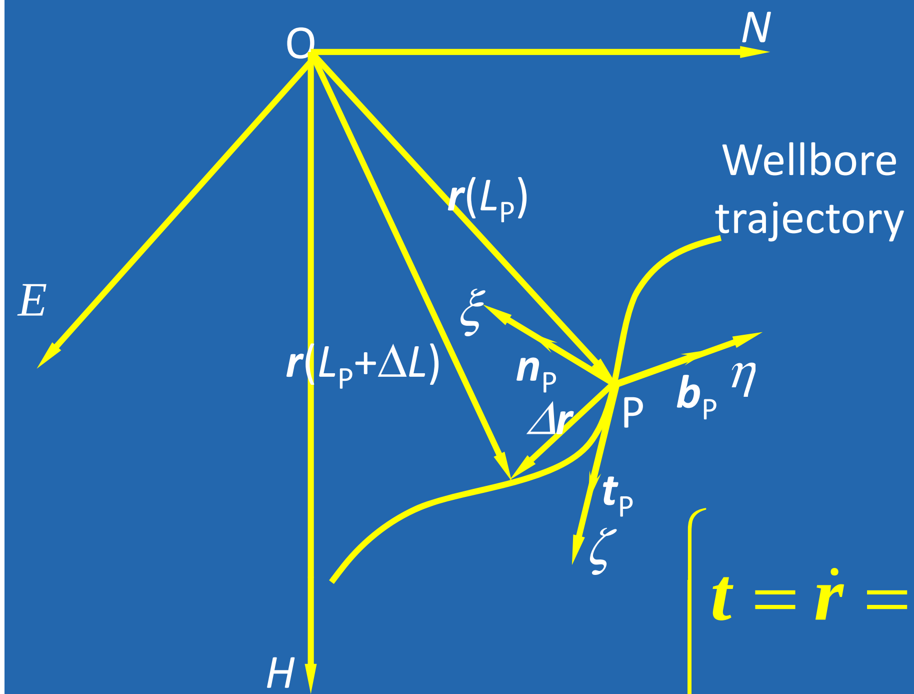
- Bending Moment discontinuity

Torsion is discontinuous

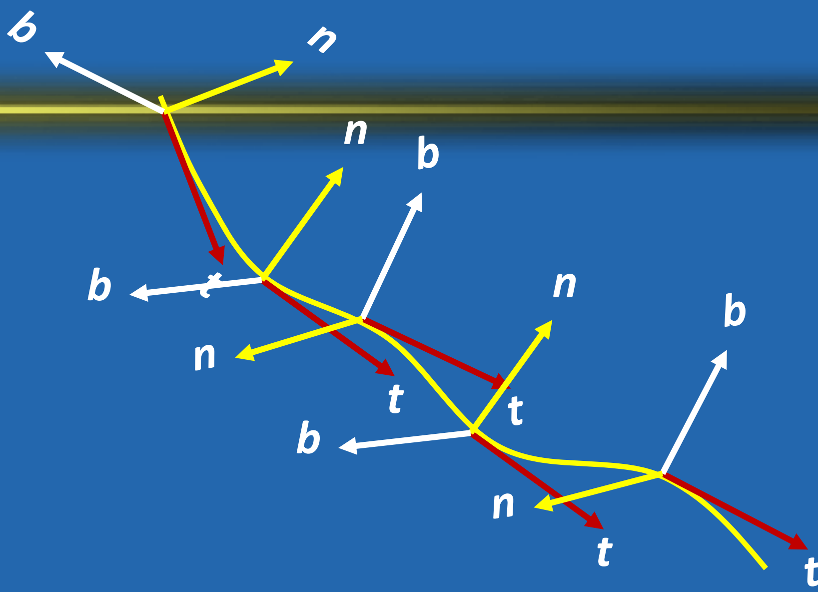
- Shear Force discontinuity

Tubular, downhole tool and SAG problems !!!

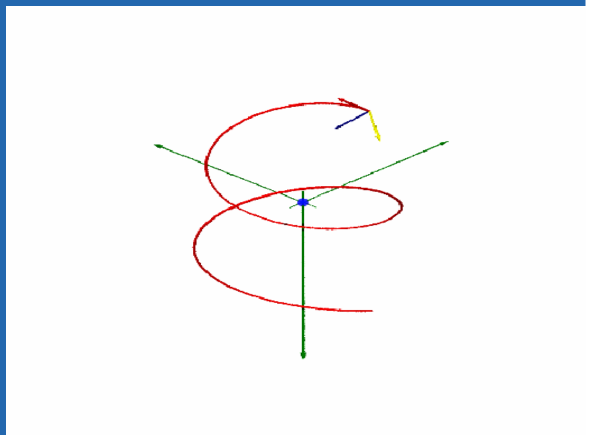
Wellbore Torsion



$$
\begin{cases}
\boldsymbol{t} = \dot{\boldsymbol{r}} = \dfrac{d\boldsymbol{r}}{dL} \\
\boldsymbol{n} = \dfrac{\dot{\boldsymbol{t}}}{|\dot{\boldsymbol{t}}|} = \dfrac{\ddot{\boldsymbol{r}}}{|\ddot{\boldsymbol{r}}|} \\
\boldsymbol{b} = \boldsymbol{t} \times \boldsymbol{n}
\end{cases}
$$



Frenet Frame



Wellbore Torsion

- Wellbore Curvature

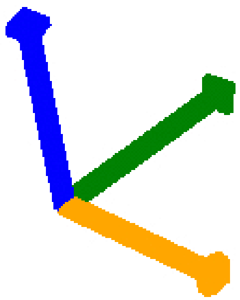
$$\kappa = \left|\frac{d\mathbf{t}}{dL}\right| = \left|\dot{\mathbf{t}}\right| \quad \Rightarrow \quad \kappa = \sqrt{\kappa_\alpha{}^2 + \kappa_\phi{}^2 \sin^2\alpha}$$

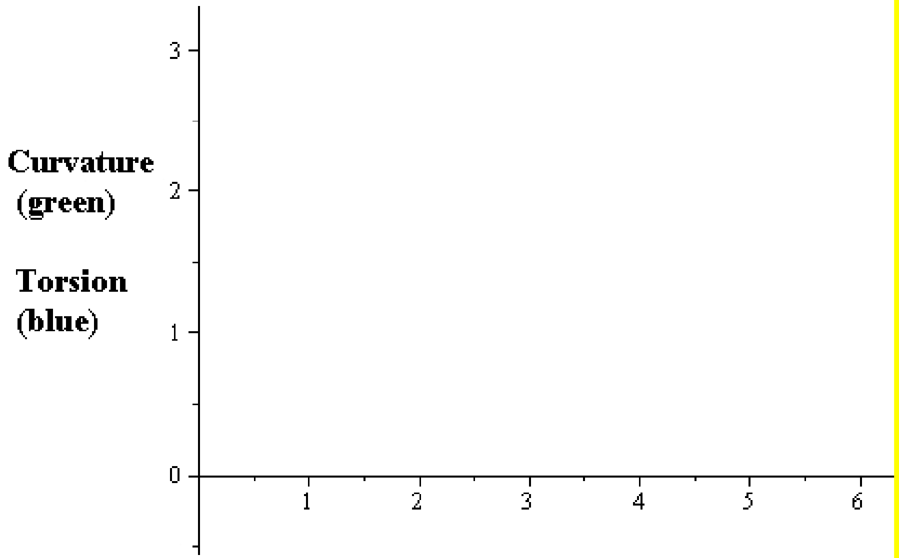
- Wellbore Torsion

$$\tau = \frac{\kappa_\alpha \dot{\kappa}_\phi - \kappa_\phi \dot{\kappa}_\alpha}{\kappa^2} \sin\alpha + \kappa_\phi \left(1 + \frac{\kappa_\alpha{}^2}{\kappa^2}\right) \cos\alpha$$

Effect of Wellbore Torsion on Borehole Drift

Tangent Vector – Yellow
Normal Vector – Green
Binormal Vector - Blue



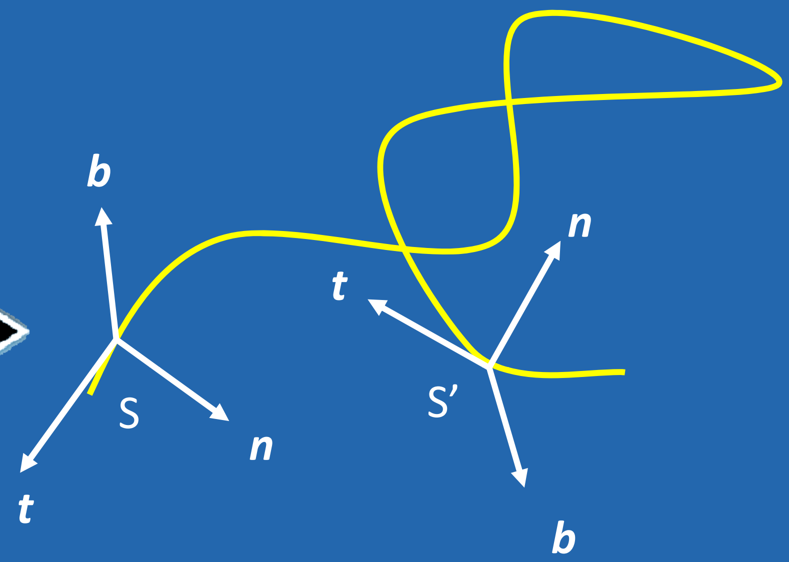


Source: en.wikipedia.org/wiki

Borehole shape

Functions for curvature and torsion will help to define the shape of the wellpath profile

Serret-Frenet equations fully describe a wellpath up to a Euclidean movement



Frenet/Moving Frame

Design Parameters

Tortuosity

Drilling Indices

Torsion

Strain Energy

Strain Energy of the Wellpath

- √ Mathematical Technique
- √ Physical and geometrical principles
- √ Minimum Energy of the wellpath

Strain Energy of the Wellpath

Elastic Energy of a thin beam - it is characterized by bending and twisting least while passing through a given set of points.

Energy

$$E = \int_0^{\ell} \left(\kappa(x)^2 + \tau(x)^2\right) dx$$

Absolute Energy

$$E_{(abs)_n} = \left(\frac{\sum_{i=1}^{n} \left(\kappa_i^{\,2} + \tau_i^{\,2}\right) \Delta D_i}{D_n + \Delta D_n} \right)$$

Relative Energy

$$E_{s(rel)_n} = E_{s(abs)_n}^{cont} - E_{s(abs)_n}^{ncont}$$

Strain Energy of Special Wellpaths

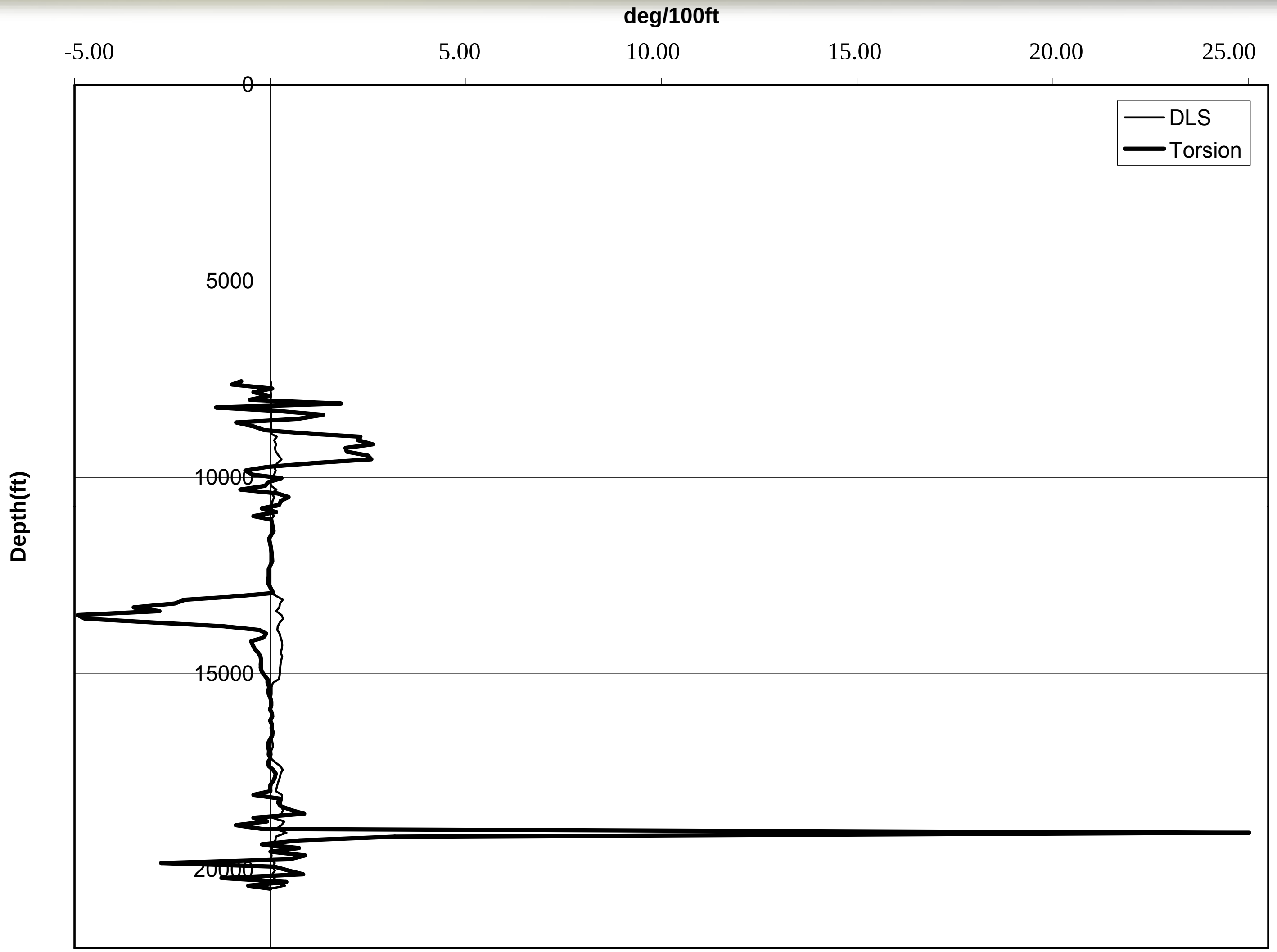
	Circular Arc	Catenary	Spiral
Curvature	$\kappa(s) = \frac{a}{\sigma^2 + b^2} u$	$\kappa(s) = \frac{180\,C}{\pi\, a} \sin^2 \alpha$	$\kappa(s) = \frac{\pi a}{\sigma^2 + b^2} u$
Torsion	$\tau(s) = \frac{b}{\sigma^2 + b^2} u$	$\tau(s) = \kappa_\phi \left(1 - \frac{\kappa_\alpha{}^2}{\kappa^2} \right) \cos \alpha$	$\tau(s) = \frac{\pi b}{\sigma^2 + b^2} u$

Energy

$$E = \int_0^{\ell} \left(\kappa(x)^2 + \tau(x)^2 \right) dx$$

Example Studies

Example 1



deg/100ft
-5.00
5.00
10.00
15.00
20.00
25.00
0
5000
10000
15000
20000
Depth(ft)
DLS
Torsion

Example 2

SURVEY RESULTS WITH CALCULATED ENERGY

L, ft	α, deg.	ϕ, deg.	TVD (ft)	DLS, (° /100ft)	TLS, (° /100ft)	Energy
10000	90	360				
10090	90	360	6366.2	0	0	0

L, ft	α, deg.	ϕ, deg.	TVD (ft)	DLS, (° /100ft)	TLS, (° /100ft)	Energy
10000	90	360				
10045	92	358		9.4	2.3	.1824
10090	90	360	6363.1	9.4	.00002	.1666

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10000	90	360				
10015	92	359		14.90	8.5	.4418
10045	90	358		7.45	2.3	.1824
10060	94	359		14.90	-8.5	.4417
10090	90	360	6363.1	7.45	.00002	.1666

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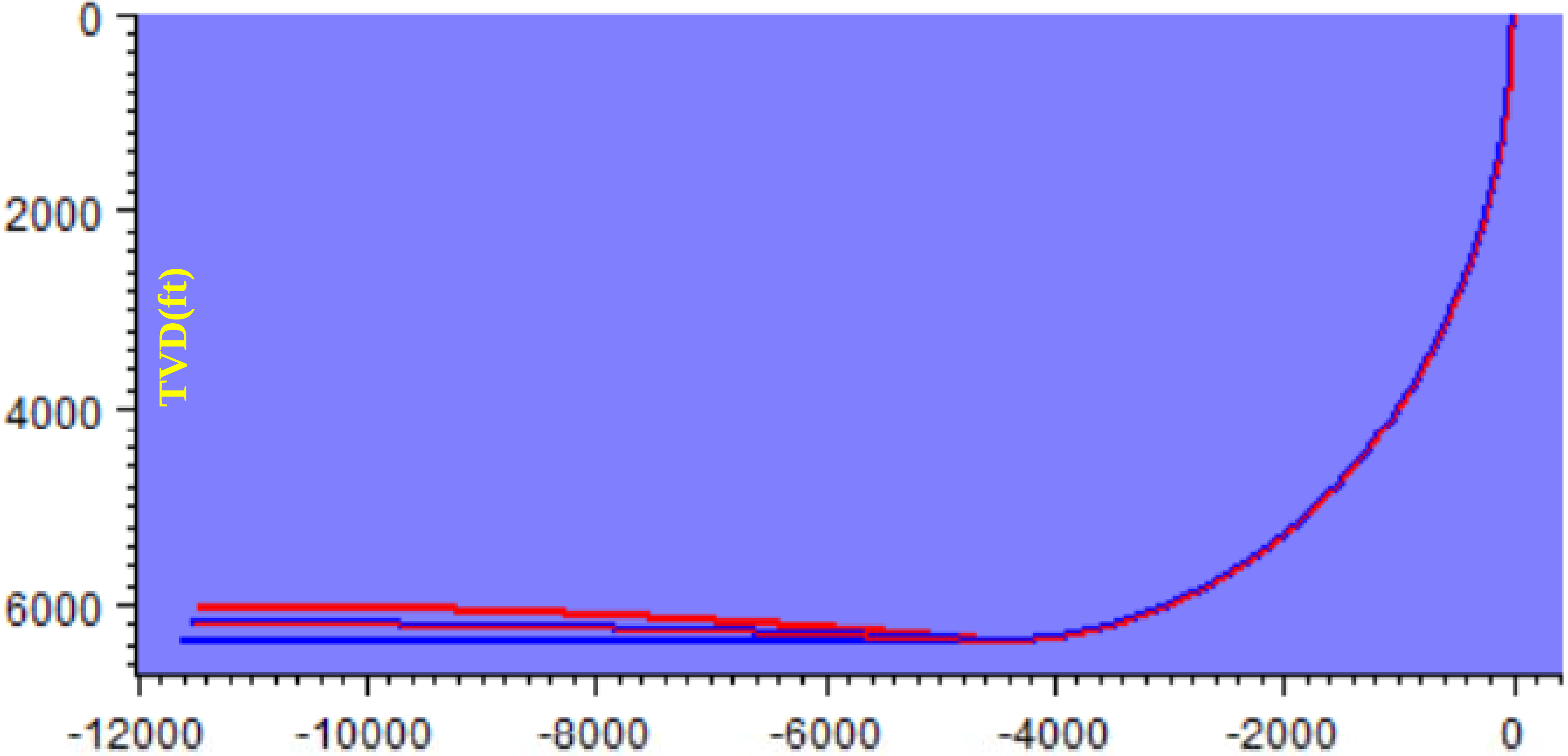
Cascading Effects

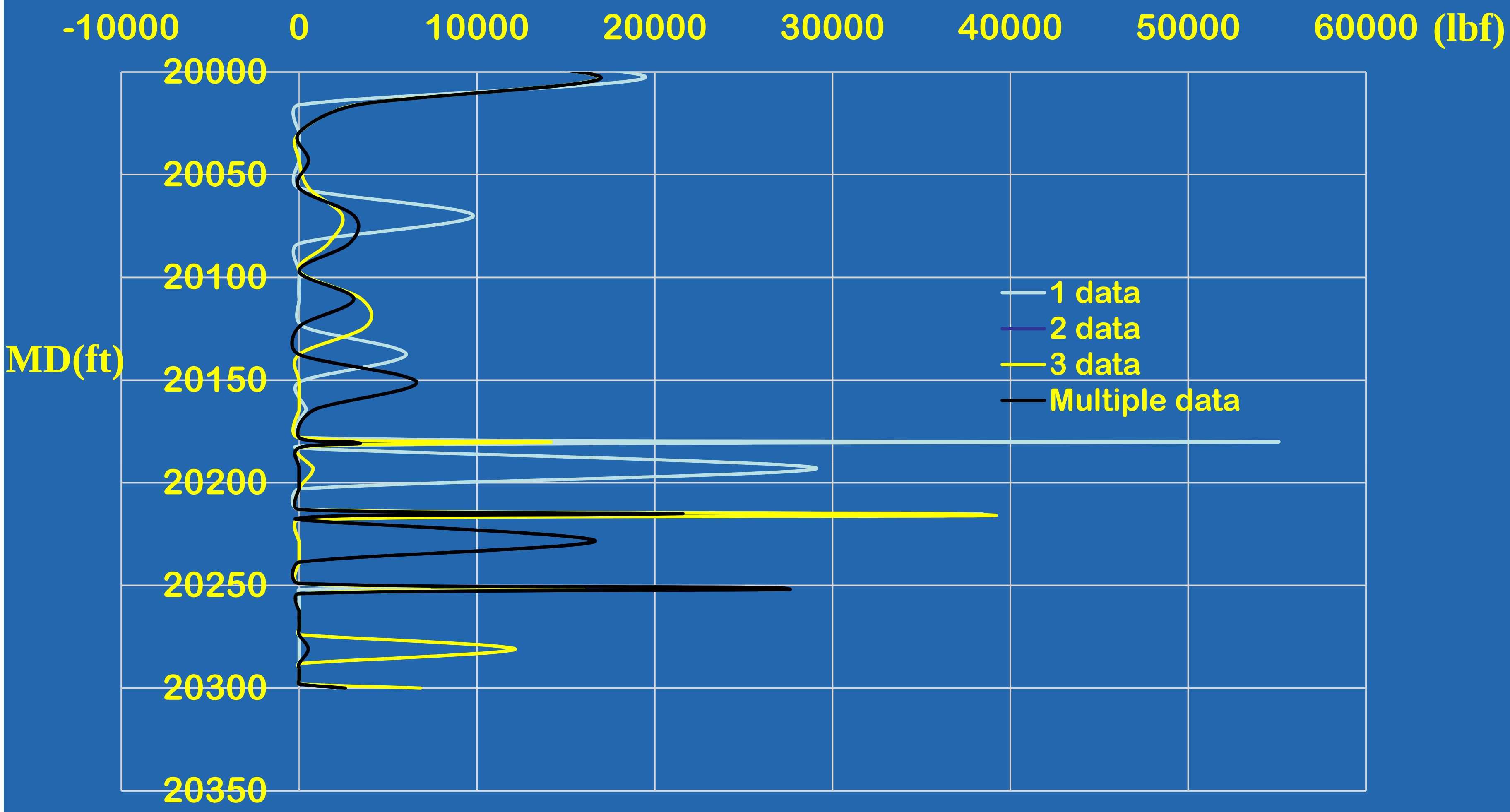
- Estimation of side force
- Estimation of drag
- Estimation of torque
- Estimation of hook load
- Estimation of friction factor
- Estimation of SAG

Vertical Section

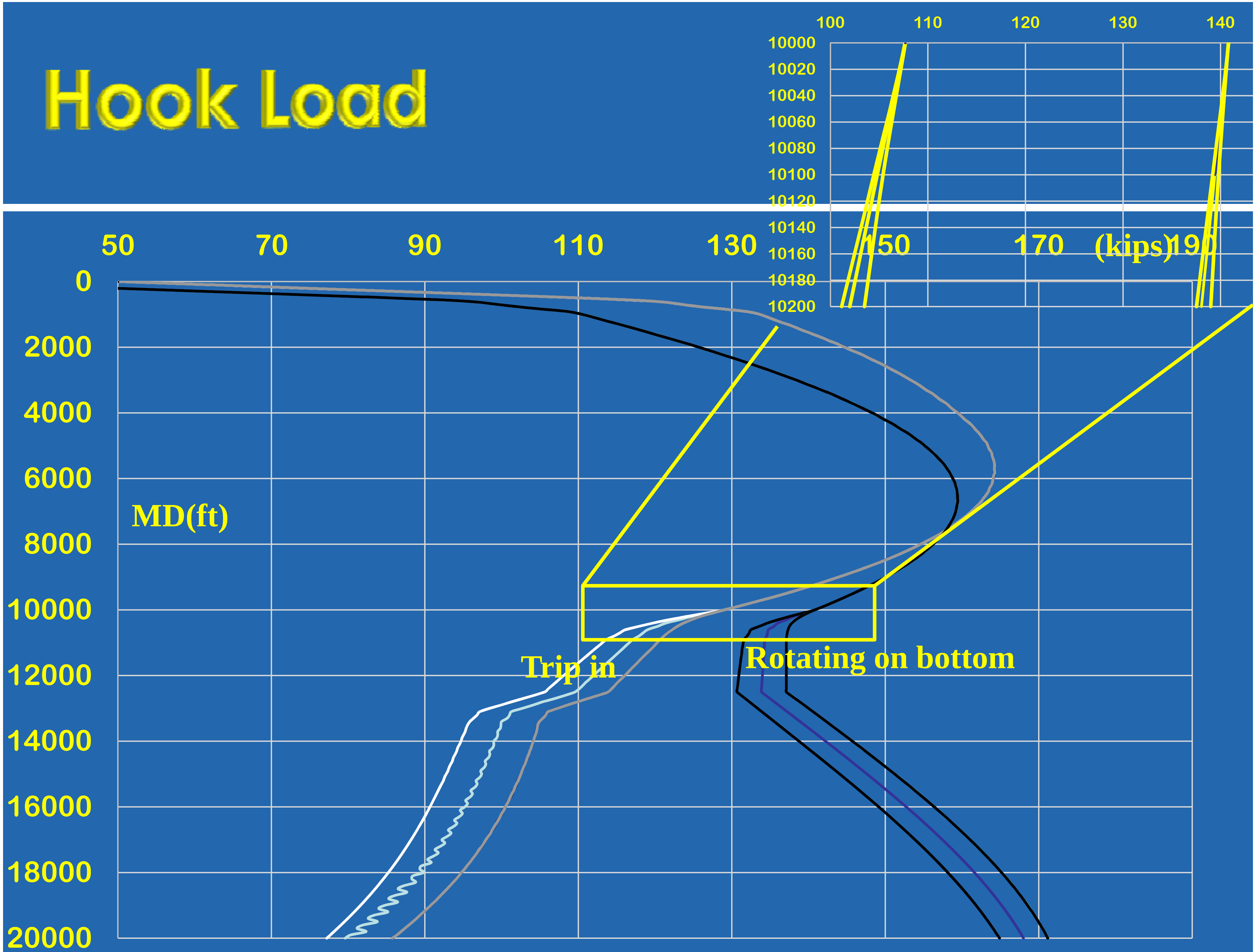


Vertical Section (ft)

Effect of Side Force



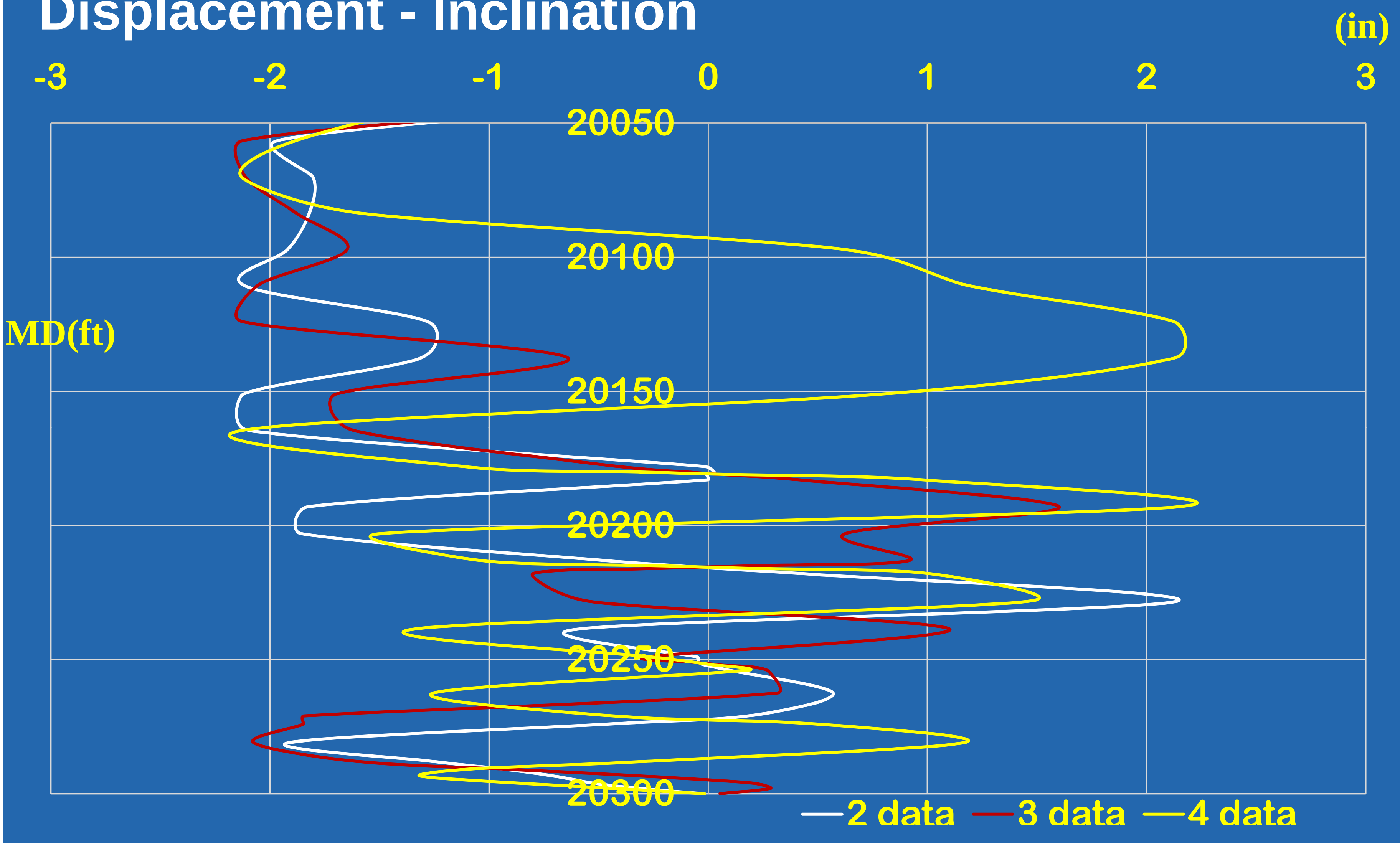
Hook Load



50
70
90
110
130
150
170
(kips)
190
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
MD(ft)
Trip in
Rotating on bottom
100
110
120
130
140
10000
10020
10040
10060
10080
10100
10120
10140
10160
10180
10200

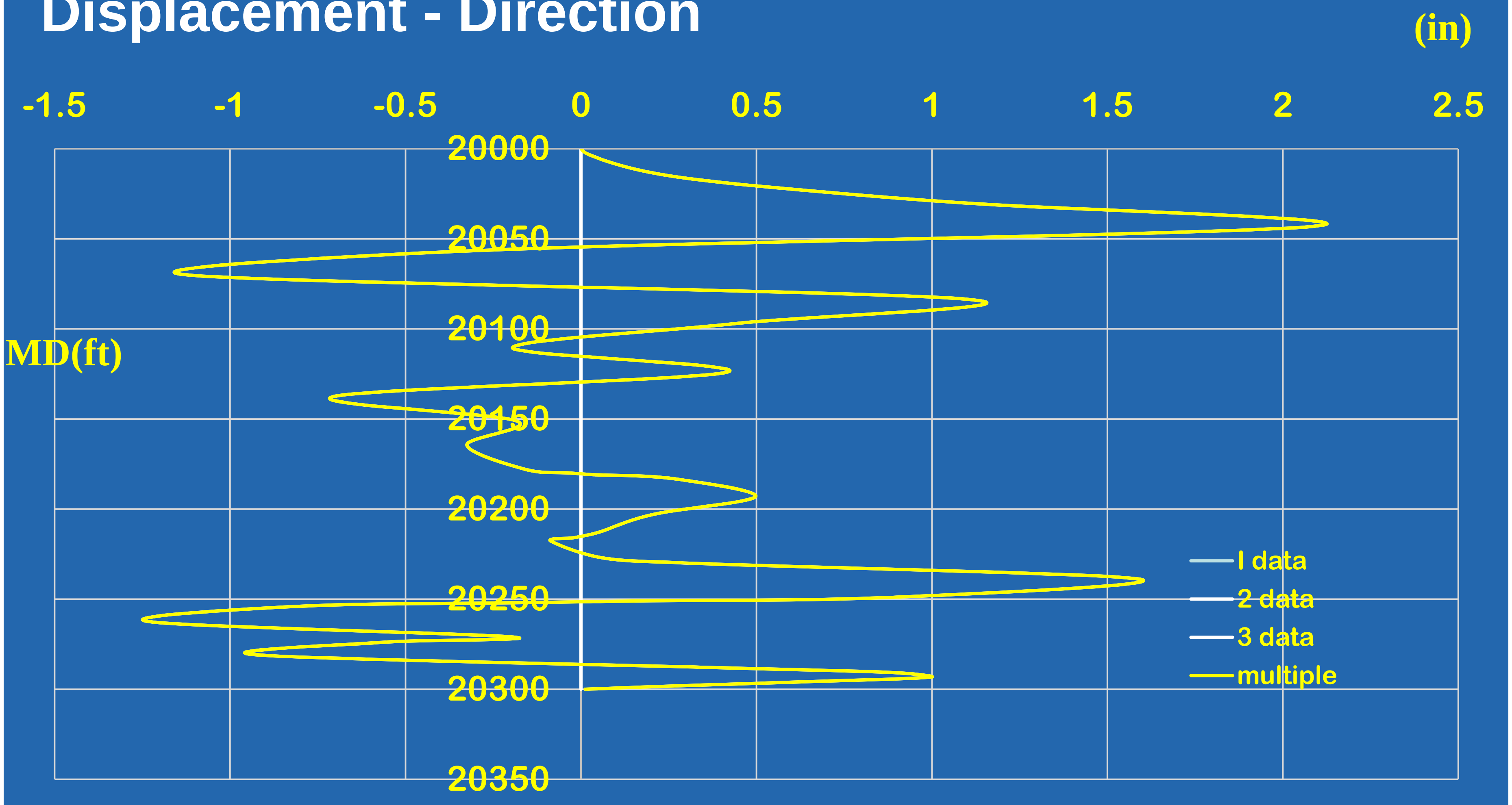
Effect of SAG

Displacement - Inclination



Effect of SAG

Displacement - Direction



Conclusions

1. Wellbore curvature and torsion at survey stations well define the shape of a wellbore within a survey interval.
2. 3D energy based criterion provides a method to compare the wellpath profiles with different survey intervals
3. The results are more precise when the wellbore curvature and torsion are synchronously involved over every course length.
4. Mechanical calculations will be skewed

Q&A

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