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Recent Advances in Complex Well Design

Phil Pattillo, BP EPTG - Houston

Overview

- New loads and limitations
  - Thermal effects – annular pressure build-up
  - Designing with limited casing bore
  - Extreme landing tools
- Beyond “API designs”
  - Probabilistic design considerations
  - ISO 10400

Annular Pressure Build-up (APB)

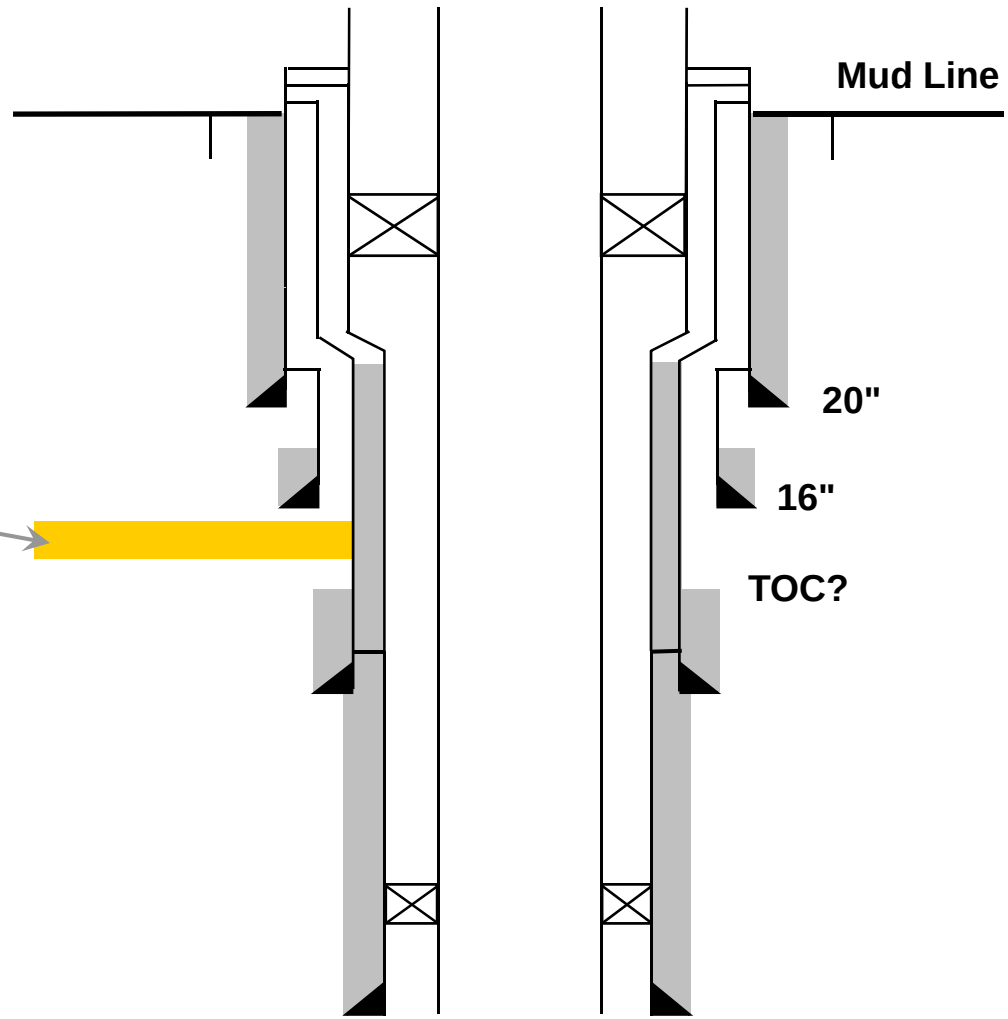
Annular Pressure Buildup (APB)

- Origin of APB loads
- Mitigating APB
  - Principles and solution categories
  - Specific well construction tools

16 in. casing collapse from APB during circulation →

The origin of APB

What do we do about this hydrocarbon bearing zone?



APB depends on

- Mechanical and thermal properties of fluid
- Flexibility of the confining boundary
- Temperature increase

Considering the fluid component,

$$\Delta V_f = V_f \left[\alpha_f \Delta T - \frac{1}{C_f} \Delta p \right]$$

Mitigating APB

Brute Force

- Thick-walled casing

Fluid Properties

- Foam spacer
- Fluids with low psi/F
- Cement entire annulus

Control the Load

- Vacuum Insulated Tubing (VIT)
- Nitrogen blanket
- Gelled brine
- Connection leak integrity
- Initial annulus pressure

Container Flexibility

- Vent the annulus
  - Active path to surface
  - Relief mechanism
    - Formation fracture/TOC
    - Rupture disks
    - Grooved casing
- Annulus communication
- Syntactic foam
- Avoid trapped pressures external to annulus

Mitigating APB

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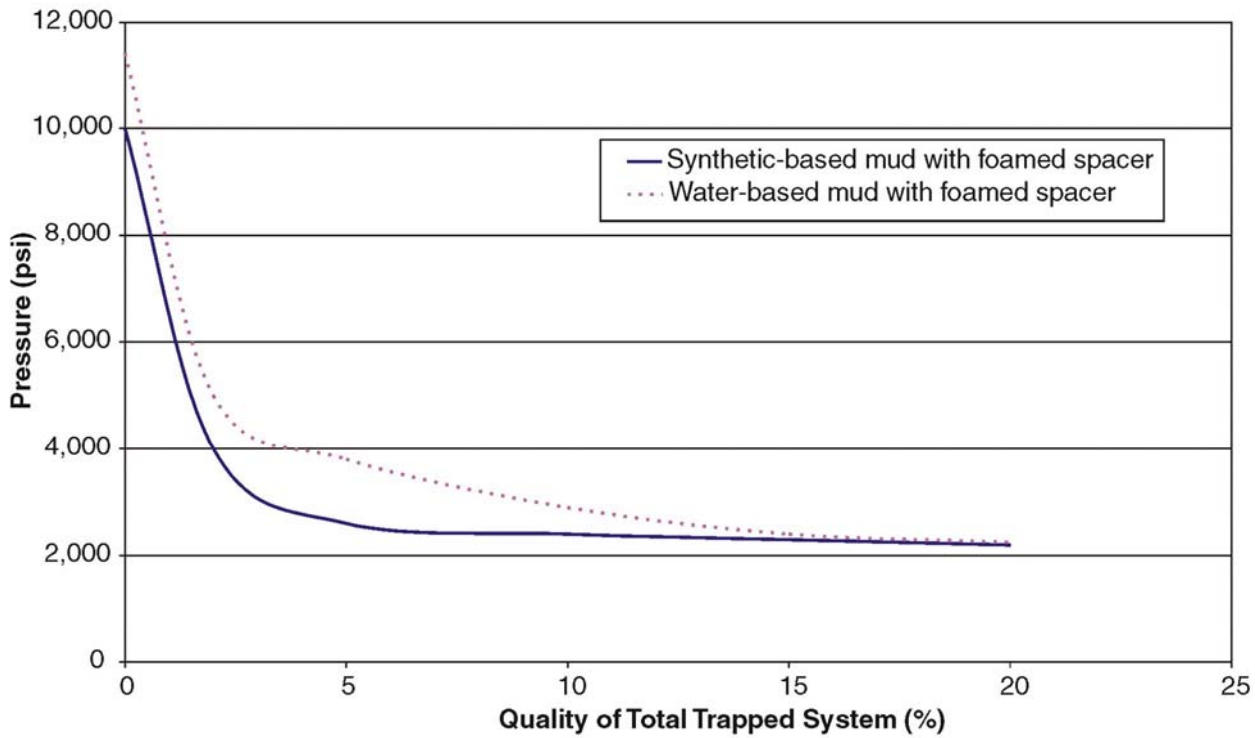

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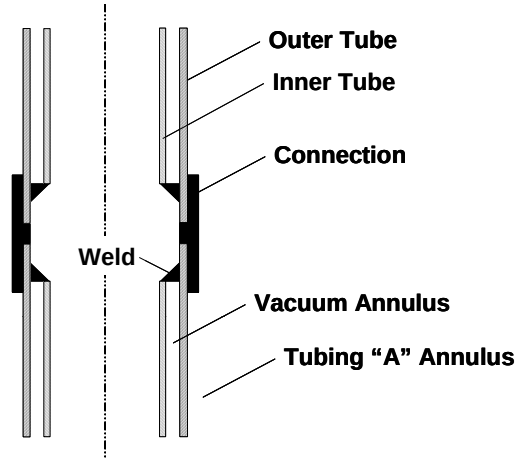
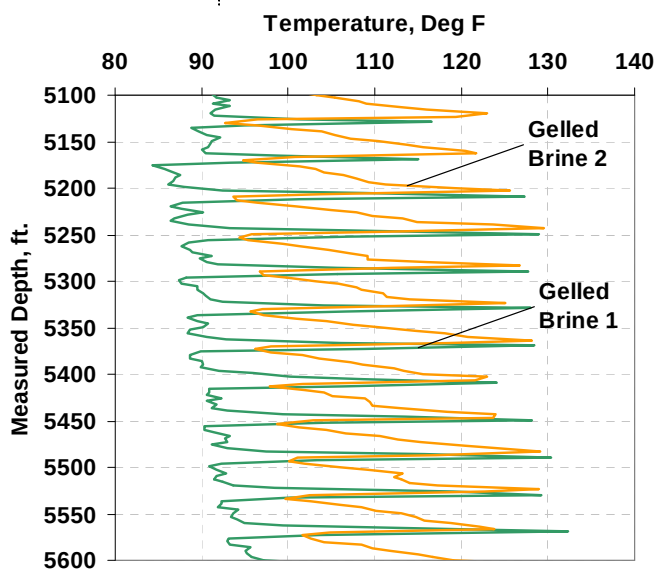
Mitigating APB





Control the Load

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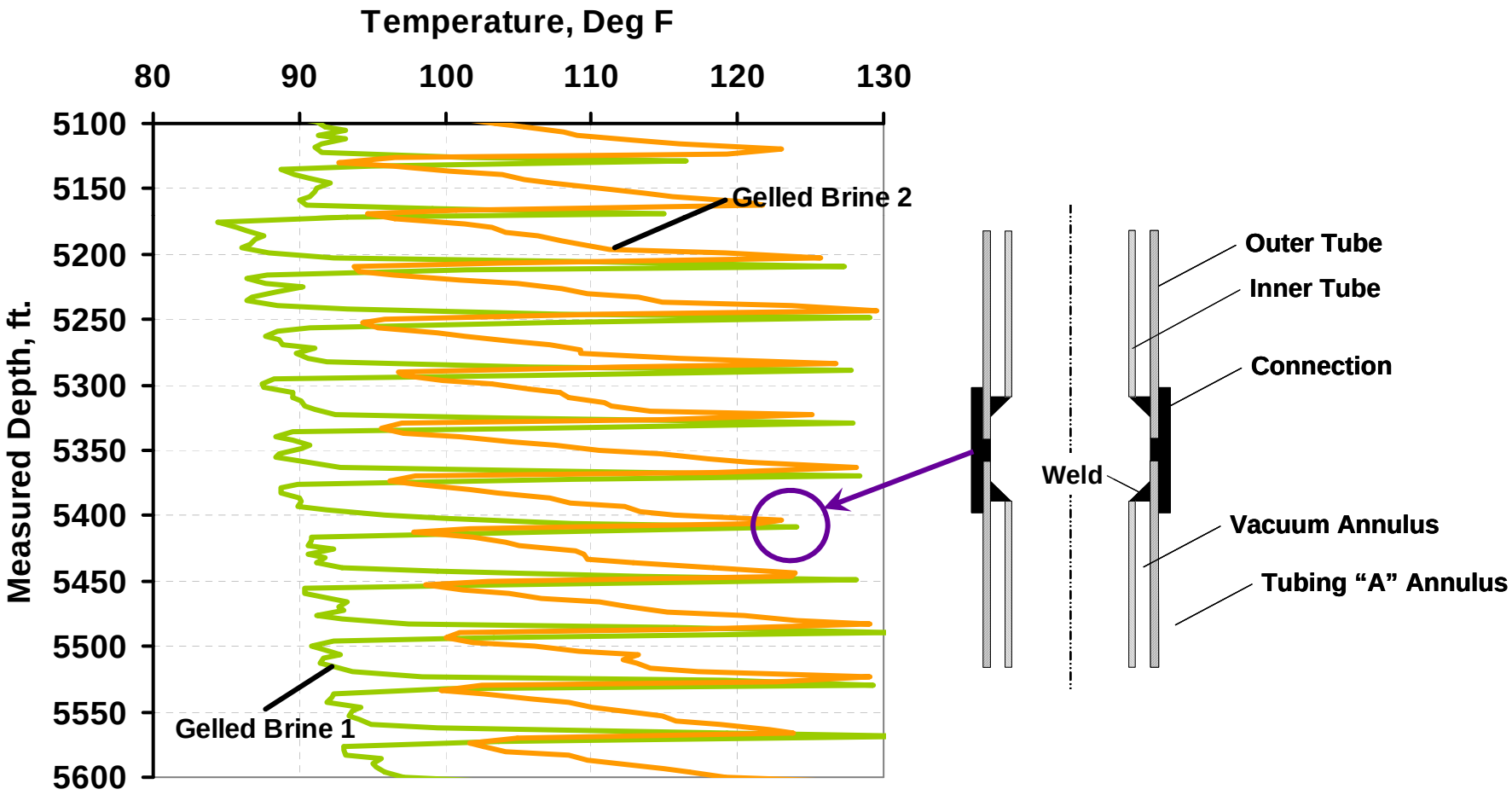
- Nitrogen blanket
- Gelled brine
- Connection leak integrity
- Initial annulus pressure

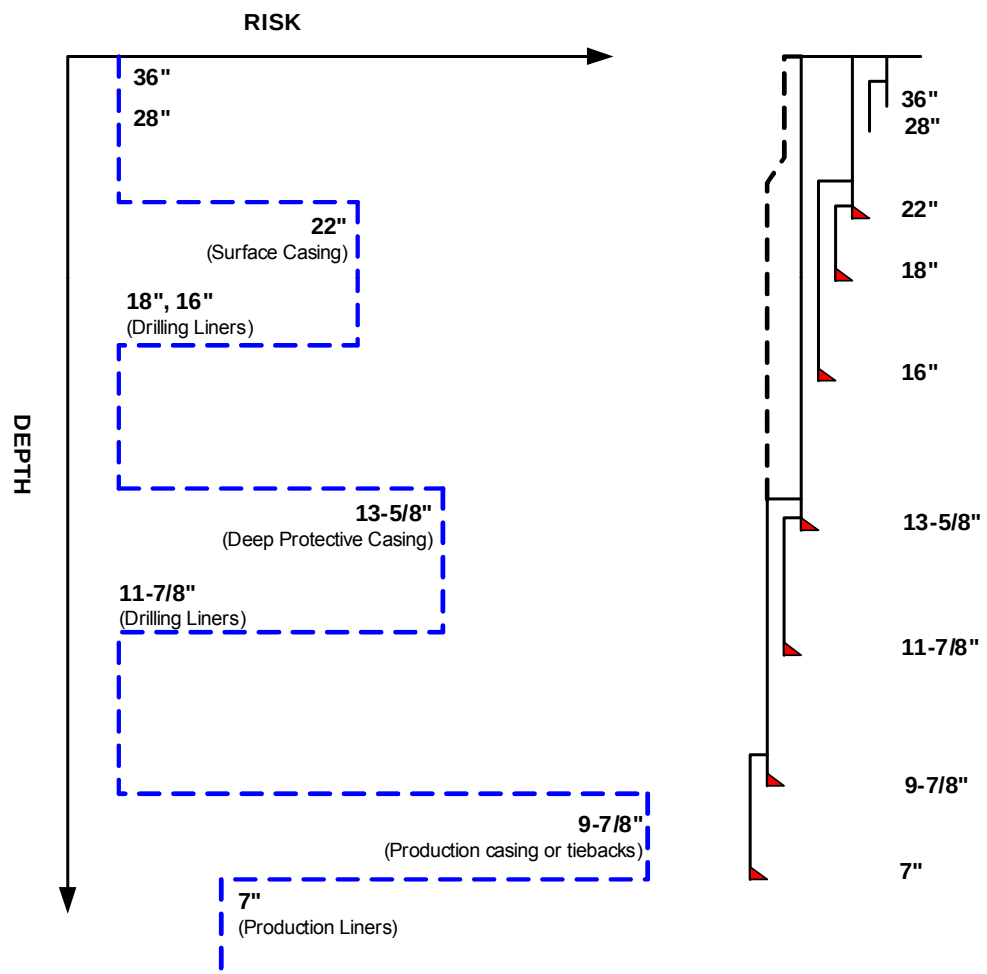
Mitigating APB – Vacuum Insulated Tubing (VIT)



Designing within wellbore limitations

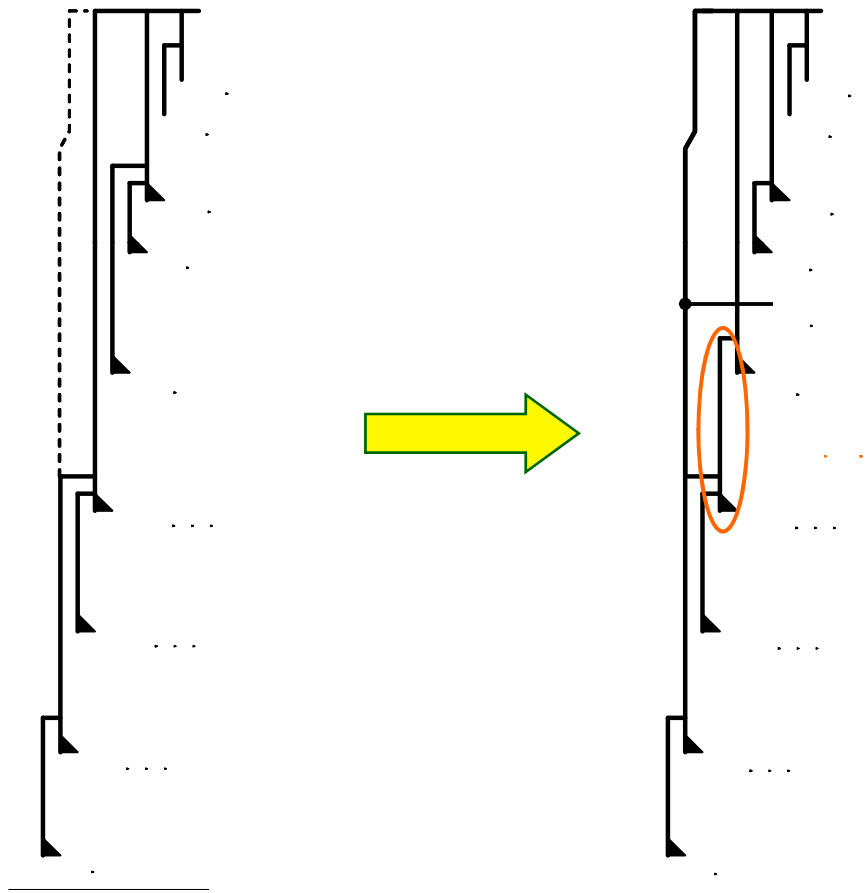
Deepwater HPHT wells, maintaining hole size

- Geometric constraints
  - Minimum → production tubulars, SSSV
  - Maximum → 18-3/4 in. bore
- Possible solutions
  - Riserless drilling
  - Managed pressure drilling
  - Designer muds
  - **Revisit casing risk profile**
    - Probability x consequence
    - Recovery
    - Empirical validation
      - Solid expandable liners



Maintaining hole size - example

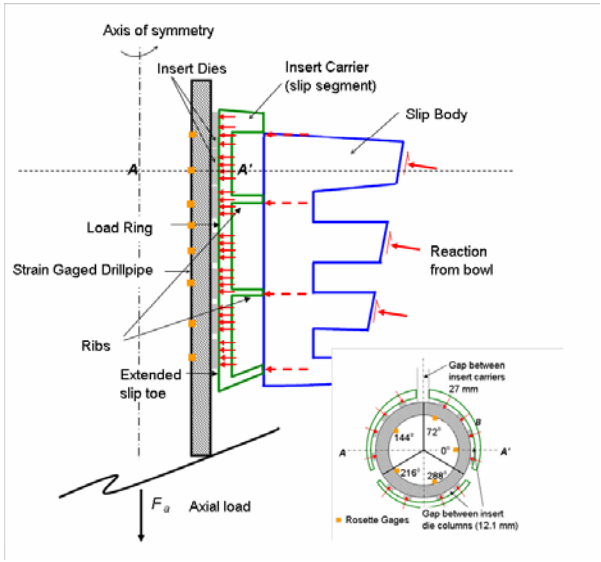
- 8-1/2 in. hole on bottom
- Production tubulars with 18,000+ psi internal yield
- 5-1/2 in. tubing
- 9-3/8 in. upper tieback drift (subsurface safety valve)
- Clearance outside tieback for APB mitigation (syntactic foam)

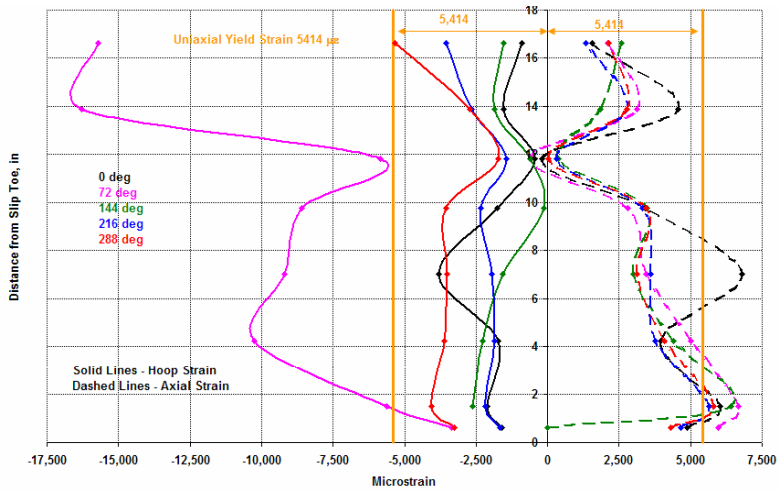


Extreme landing loads

Landing strings and slip crushing

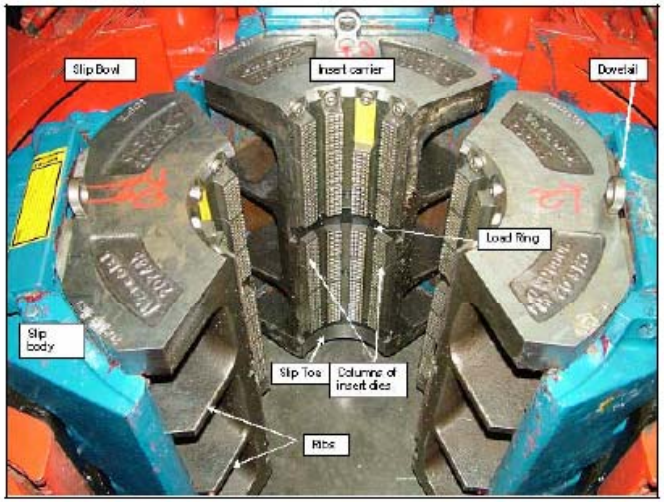
- Landing string static loads approaching 1.5 mm lbs
  - Impulse load during tripping
  - Heave induced excitation
- Applicability of Reinhold-Spiri
  - To current systems?
  - To other slip problems?

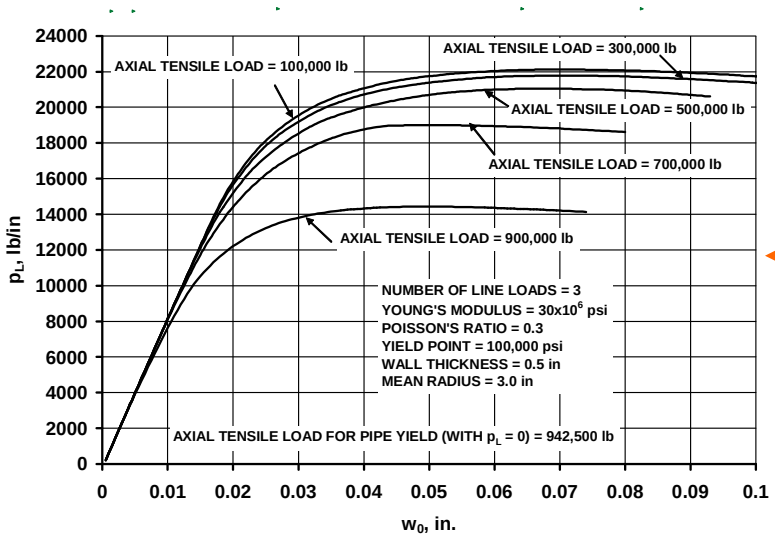


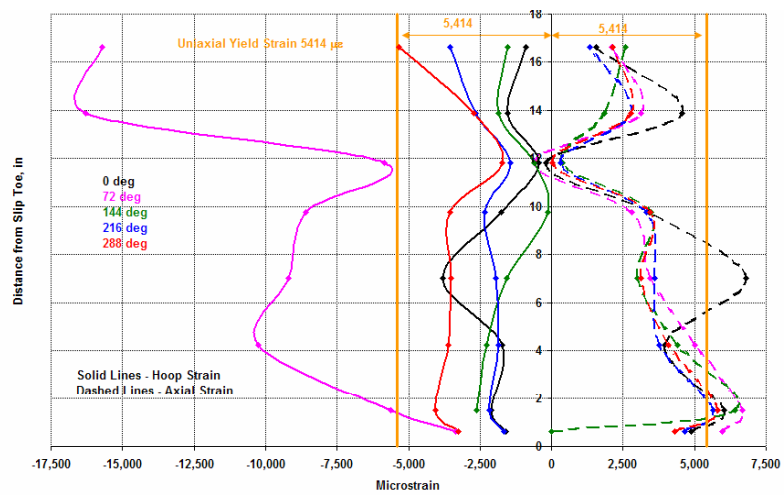


Understanding slip systems

- Strain gauged samples indicate
  - Non-uniform loading
  - Worst loading may be between inserts



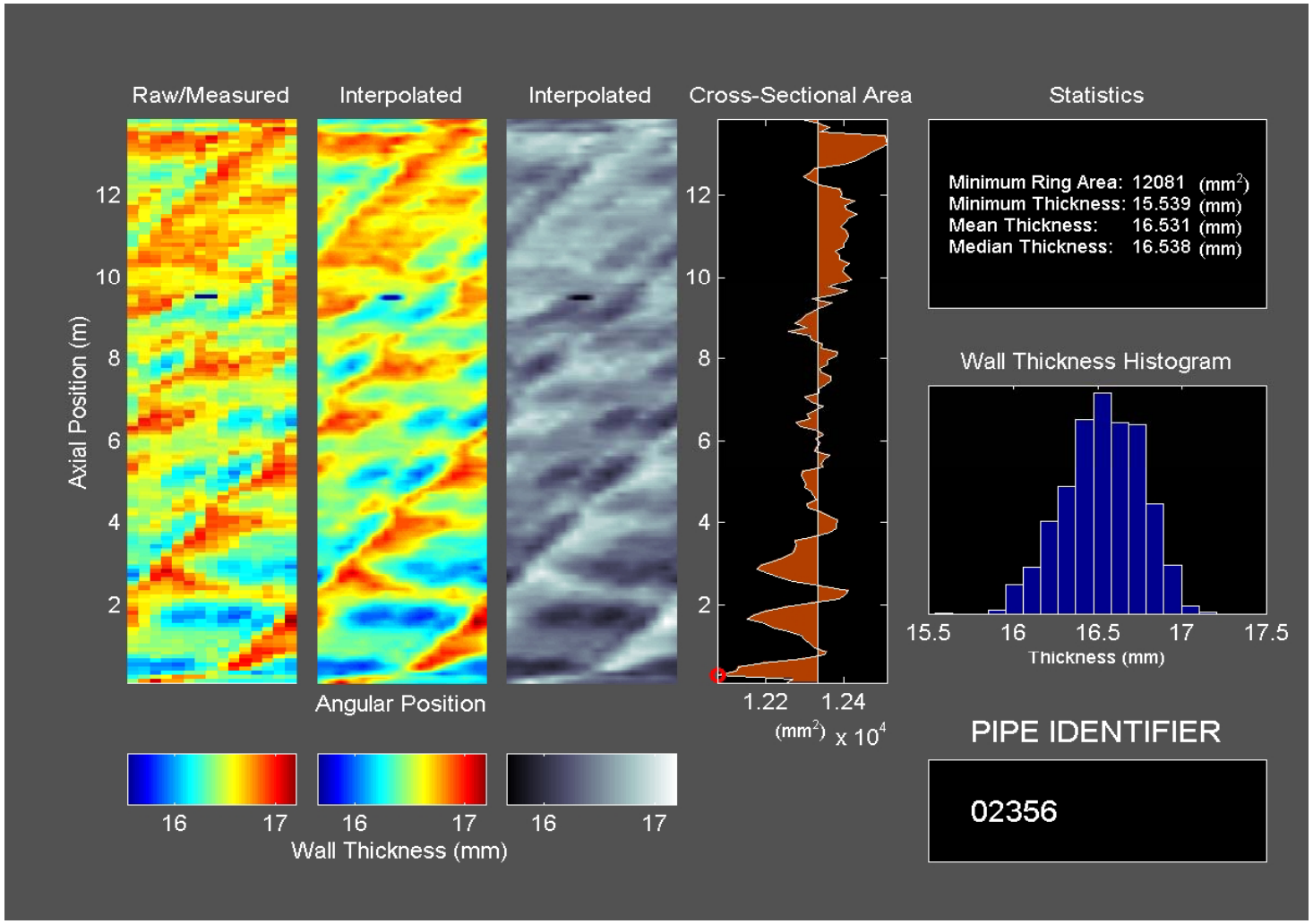




Probabilistic design considerations

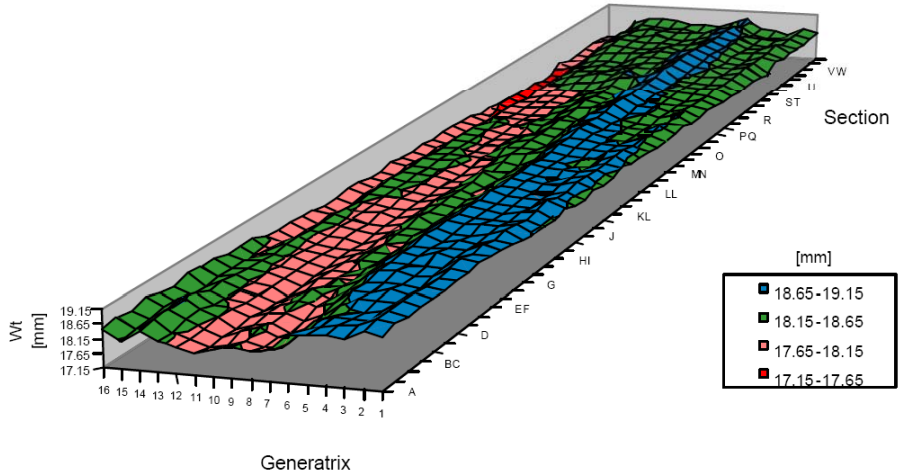
Detailed inspection data

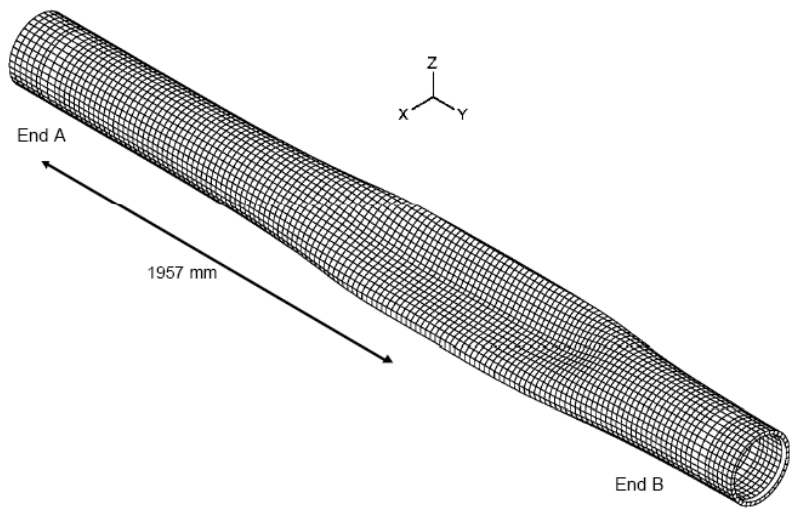
Application – calculation of cross-sectional area



Application – detailed collapse prediction

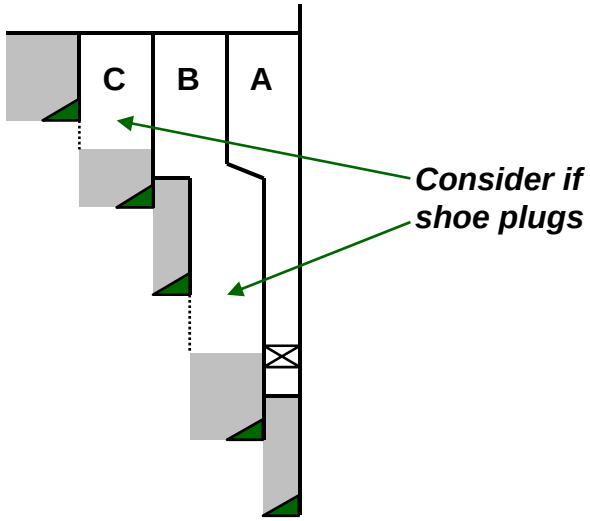
- Line pipe samples
  - X65, D/t 16-18+
- Detailed input
  - Wall, diameter
  - Axial, hoop σ-ε coupons
  - Residual stress
- Full scale tests
  - Pressure with bending
  - Collapse, propagation
- Excellent results (<3% no bending, 0-9% with bending)

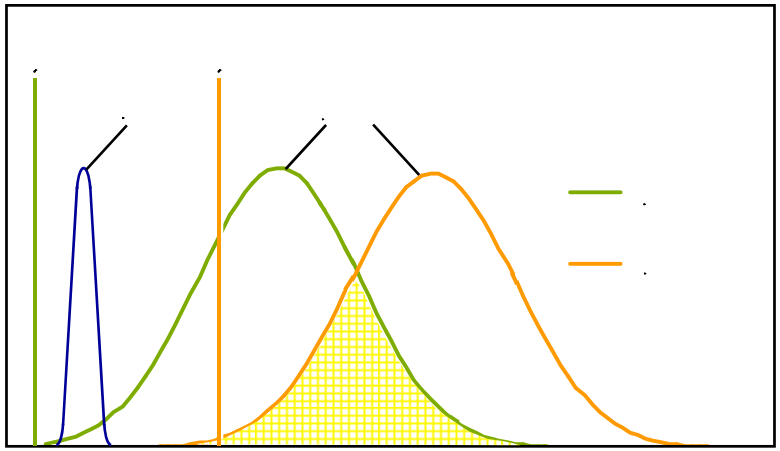




Probabilistic advantage using rupture disks

- Disk pressures have tight, controlled tolerances (± 5% on rupture pressure)
- Contrast with 12.5% wall tolerance and 10-30 ksi tensile strength variation for casing body
  - Wide uncertainty of casing rupture and collapse pressures
  - Cannot count on outer string failing first





ISO 10400 (New API 5C3)

Clause	Subject	Comments
1-5	Introduction, symbols	
6	Triaxial yield	**von Mises yield** Axial yield, internal yield pressure as special cases
7	Ductile rupture	**All new**
8-17	Collapse, connections, mass, elongation, etc.	Identical to existing formulas
Annexes	Details, derivations, performance property tables	**Probabilistic properties** (from performance or production data)

Conclusions

- No lack of challenging problems
  - Continuing research on annular pressure mitigation
  - Rethinking old solutions
- Design stretch via probability
  - Increasing support from standards