Coiled Tubing BHA's

- What is needed to do the job?
- What can go wrong?
- What do you need to get out of trouble?
- How could you prevent it?
- Where are the "needed" tools, talent, equip, fluids, etc, located?

CT Well Service Usages

Fluid Placement & Cleanout - 70% of use

- Cement Squeezing
- Cleanout-Norm./Rev.
- Inflatable Packers
- Chemical Stimulation
- Underreaming
- Fishing
- Plug Setting
- Downhole Camera
- Production Logging
- Shift Sliding Sleeves
- Perforating
- Fraccing
- Junk Milling
- Window Milling
- Drilling
- Etc.

Pre Rig-up Issues

- Is this the right tool for the job?
- What are lessons learned from others?
- Check CT history and model remaining life against operational requirements.
- Does your BHA and job design leave sufficient alternatives if problem countered?
- What over-pull remains at bottom of well?
- Determine operation “killers” and minimize risks.

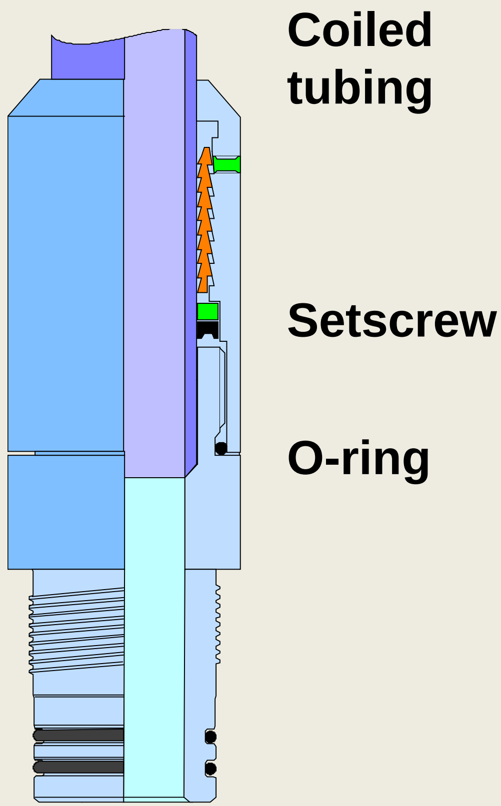
Other Rig-up Notes

- Measure all parts of the BHA (O.D.s & I.D.s)
- CT can collapse (with check valves in place) while pressure testing tubing. Be aware of differential pressures.
- Rigid extensions needed on CT to bypass GLM's?
- Any upsets or non-beveled areas on the tools?
- Hydraulic disconnects compatible with other parts of the BHA?
- BHA compatible with wellbore restrictions?

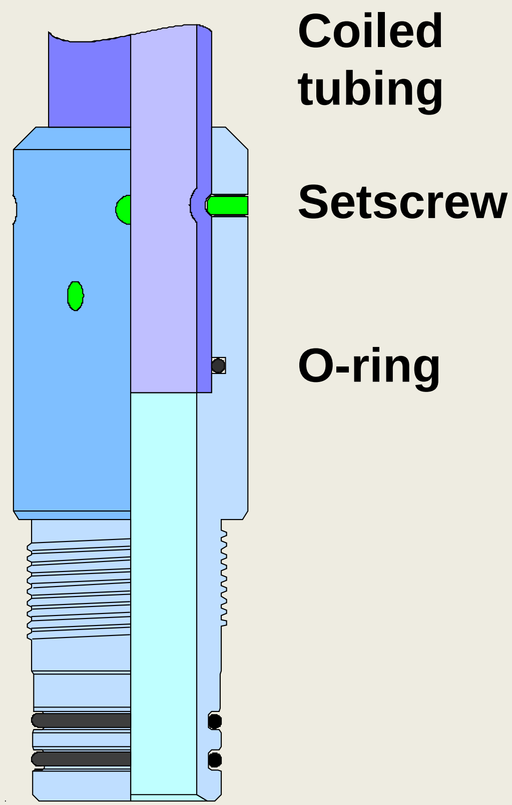
CT to Tool Connectors

- Crimp-on (Roll-on Style)
- Cold Roll (Roll-on Style)
- Dimpled Style
- Set-screw Style
- Internal Slip Style
- External Slip Style
- Combination - slip and dimpled/set-screws
- Welded
- Threaded

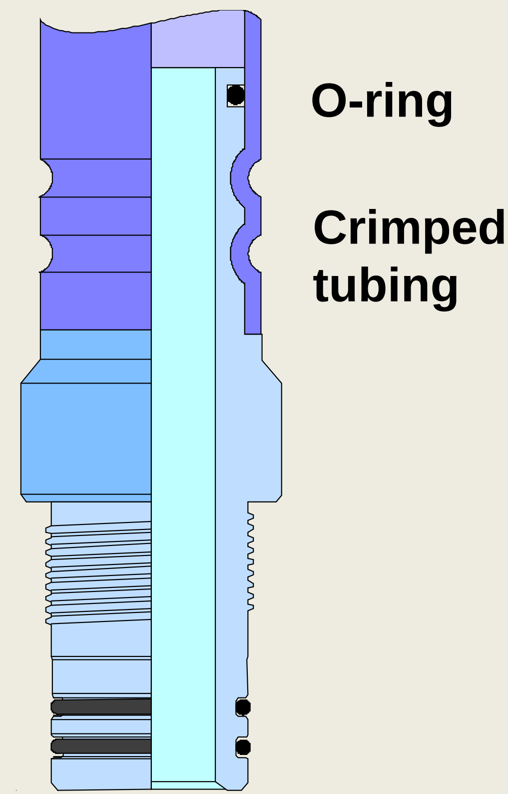
Coiled Tubing Connectors



Grapple connector

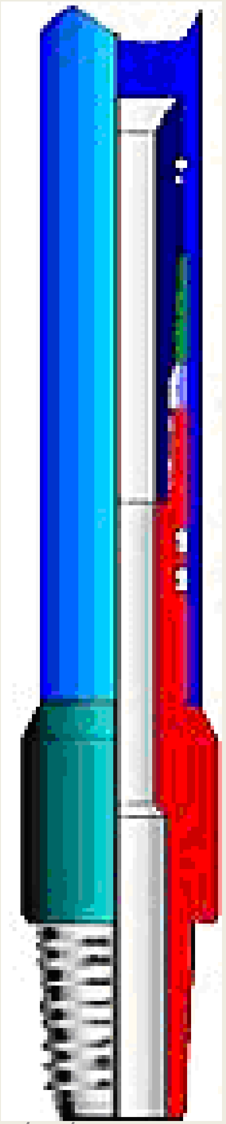


Dimple connector



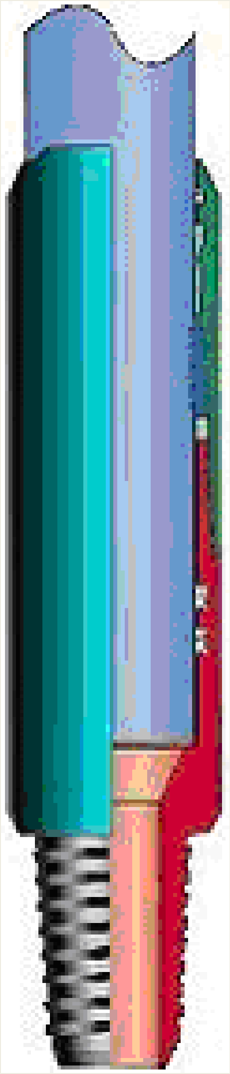
Roll-on connector

Internal Slip Style Connectors



- Strong connection
- Not effected greatly by wall reduction.
- Can be difficult to install.
- Sensitive to CT ovality.
- Reduction in I.D.
- Can be difficult to remove.

External Slip Style Connectors



- Strong connection
- Can be effected by wall reduction.
- Relatively easy to install.
- Sensitive to CT ovality.
- Widely used in the industry.

Other Connection Methods

- welding - used for bottom profiles, repair
- threaded CT - rare, usually weak (thin wall)

- Suggestion - check every connector with a pull test (and cover the hole!)

Downhole Tools

- circulation needs and effect on tool performance
- clearances (both small and large)
- weights
- functions - mixed vs single
- well deviation

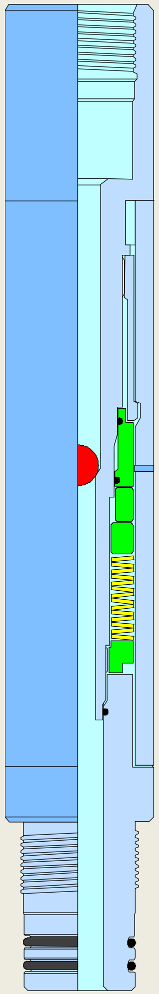
Downhole Tools

Connectors	Hydraulic Push/Pull Tools
Release Tools	Packers
Centralizers	Valves
Nozzels	Logs
Impact Tools	Perf Guns
Motors	Electric Tools
Cutters	
Underreamers	
Running Tools	
Retrieving Tools	

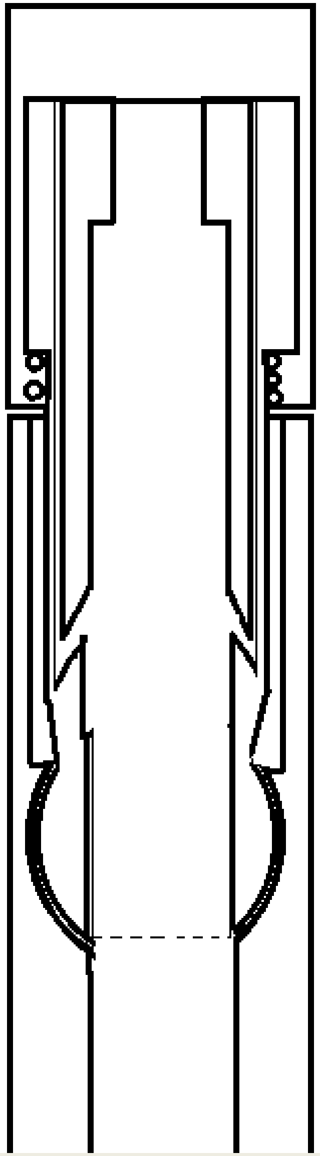
Releases

- hydraulic and ball drop releases
- rate sensitive
- trash sensitive?

Release Joints



- CT release joint
  - Releases CT from toolstring in a controlled manner
  - Resulting fishing neck on toolstring allows easy reconnection
- Release joints available with
  - Tension-activated release
  - Pressure-activated release
  - A combination of the above



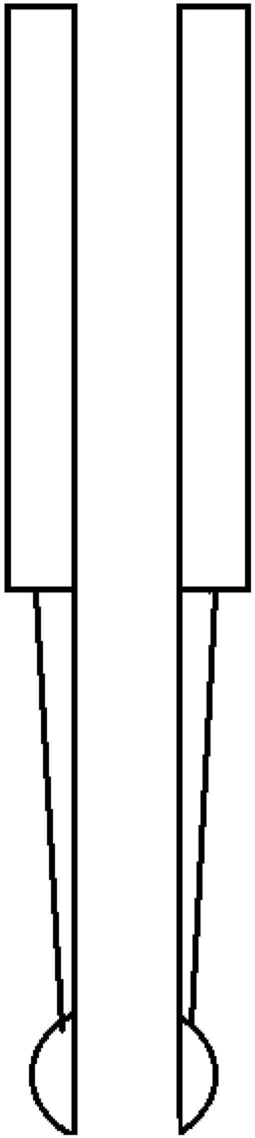
Hydraulic Disconnect

High flow rate casues inner piston to push down, drawing dogs away from bowl in bottom section of the tool.

Spring retained tools are re-settable

Can be shear pinned to withstand higher surges

Same basic tool will operate with a pump down ball.



Hydraulic Disconnect

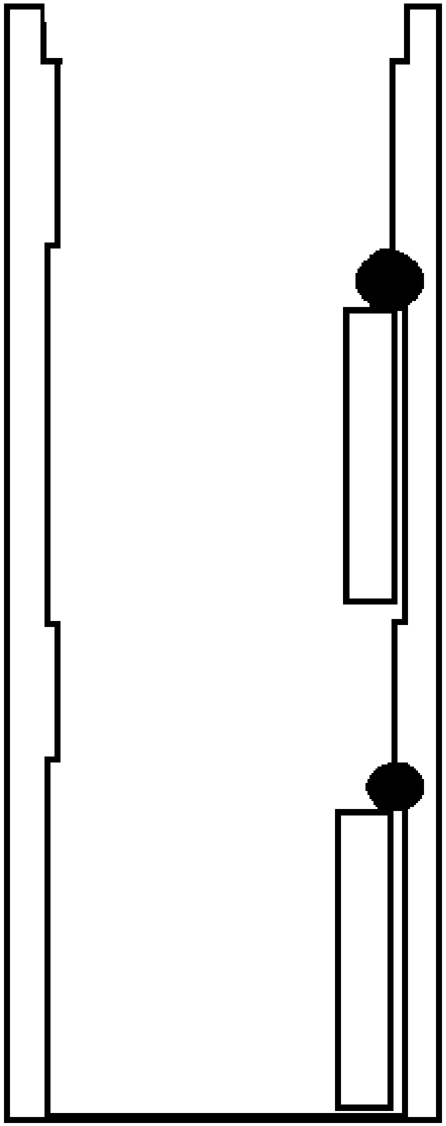
top section of tool after separation

Coiled Tubing Check Valves

- Check valves
  - Generally attached to CT connector at end of CT string
  - Prevent flow of well fluids into CT
  - Maintain well security when tubing at surface fails/damaged
  - Should be part of every CT bottomhole assembly
    - only omitted when the application precludes their use e.g., reverse circulation required

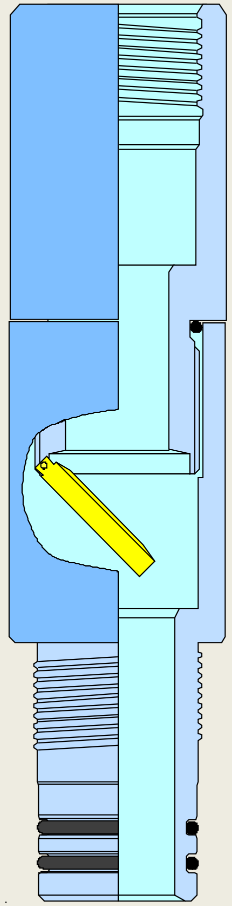
- Types of check valve
  - Flapper check valves
  - Ball and seat check valves

Flapper Check Valve

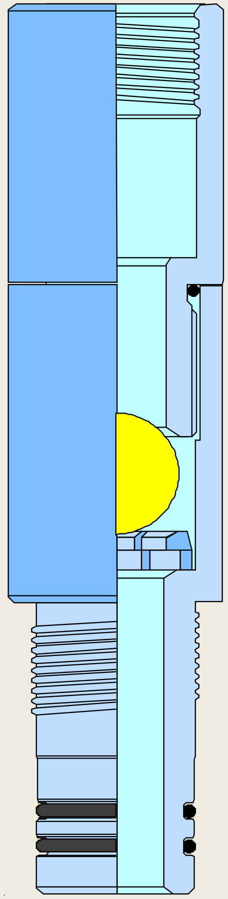


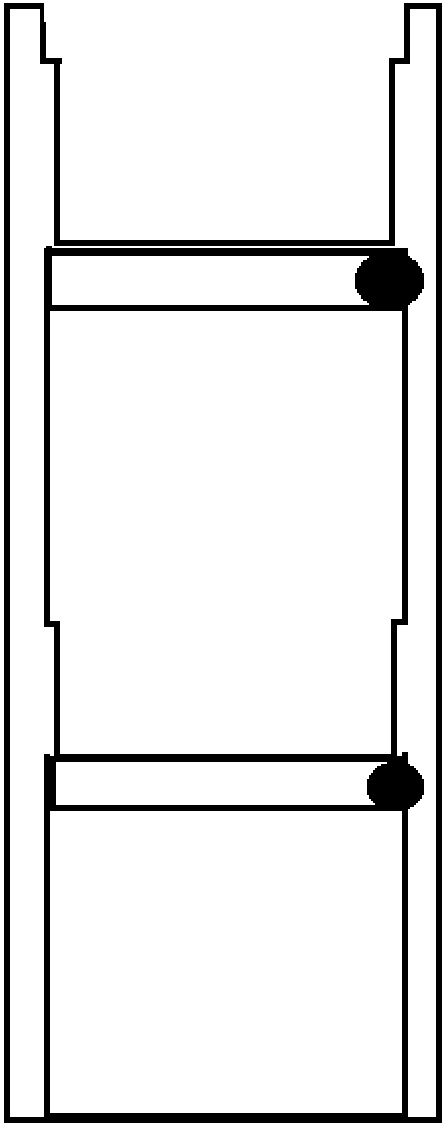
Coiled Tubing Check Valves

Flapper check valve assembly



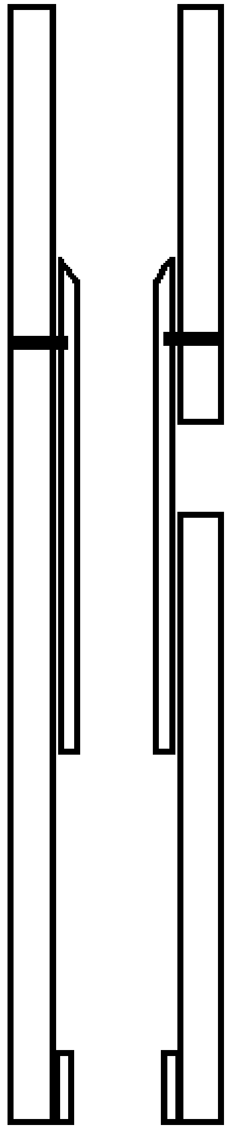
Ball and seat check valve assembly

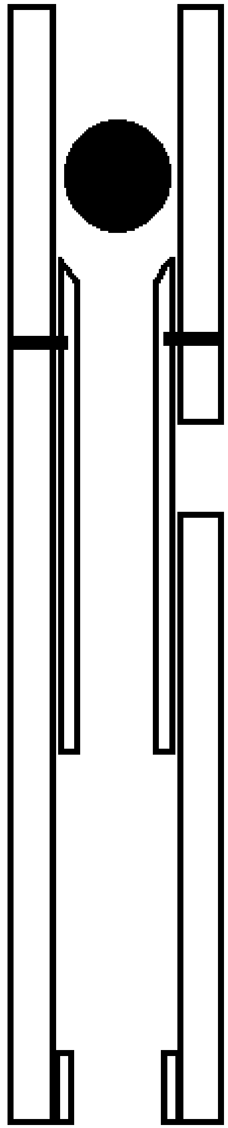


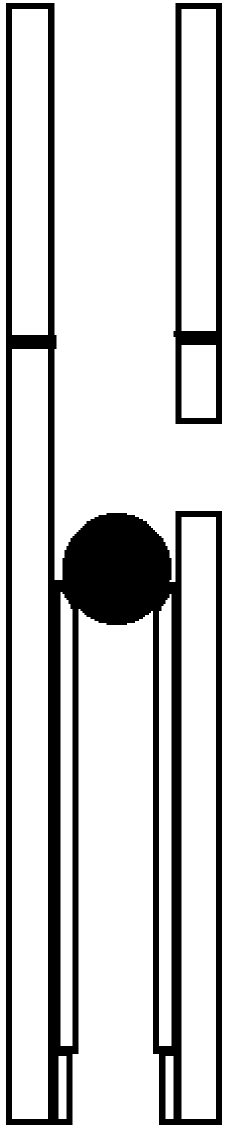


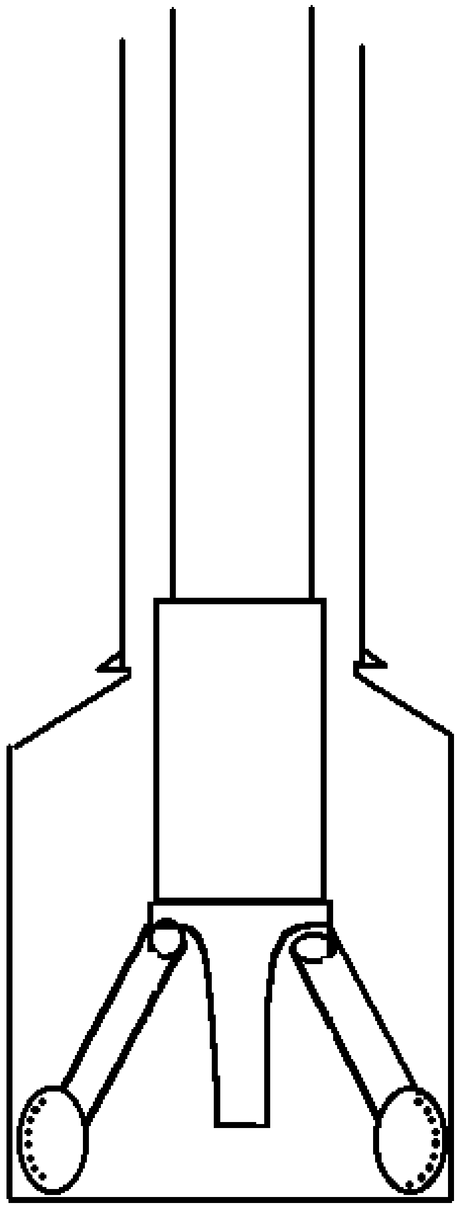
Flapper Check Valve
(valves closed)

Cirulating Port

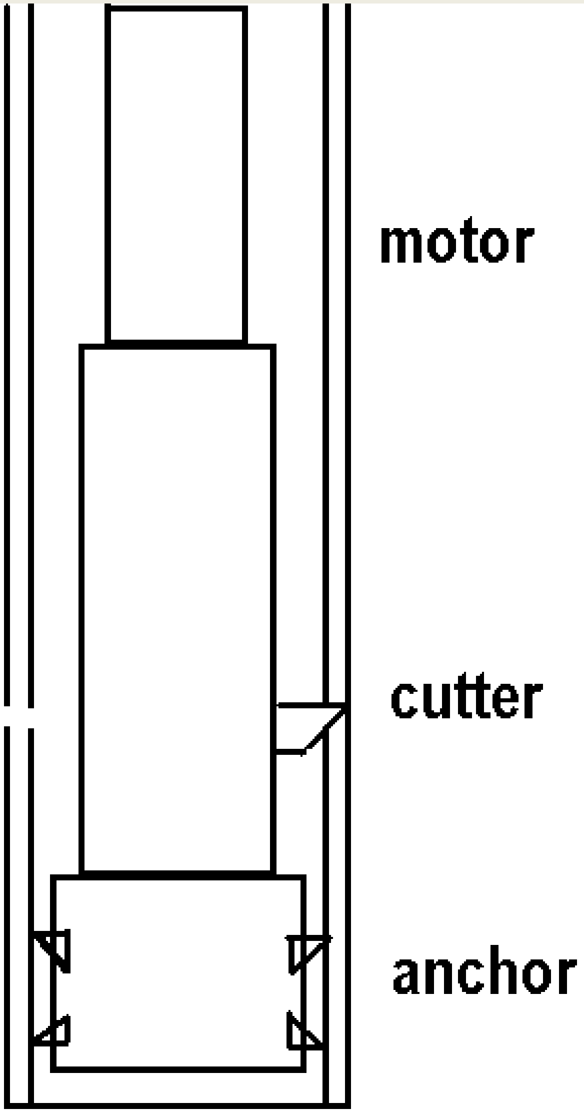


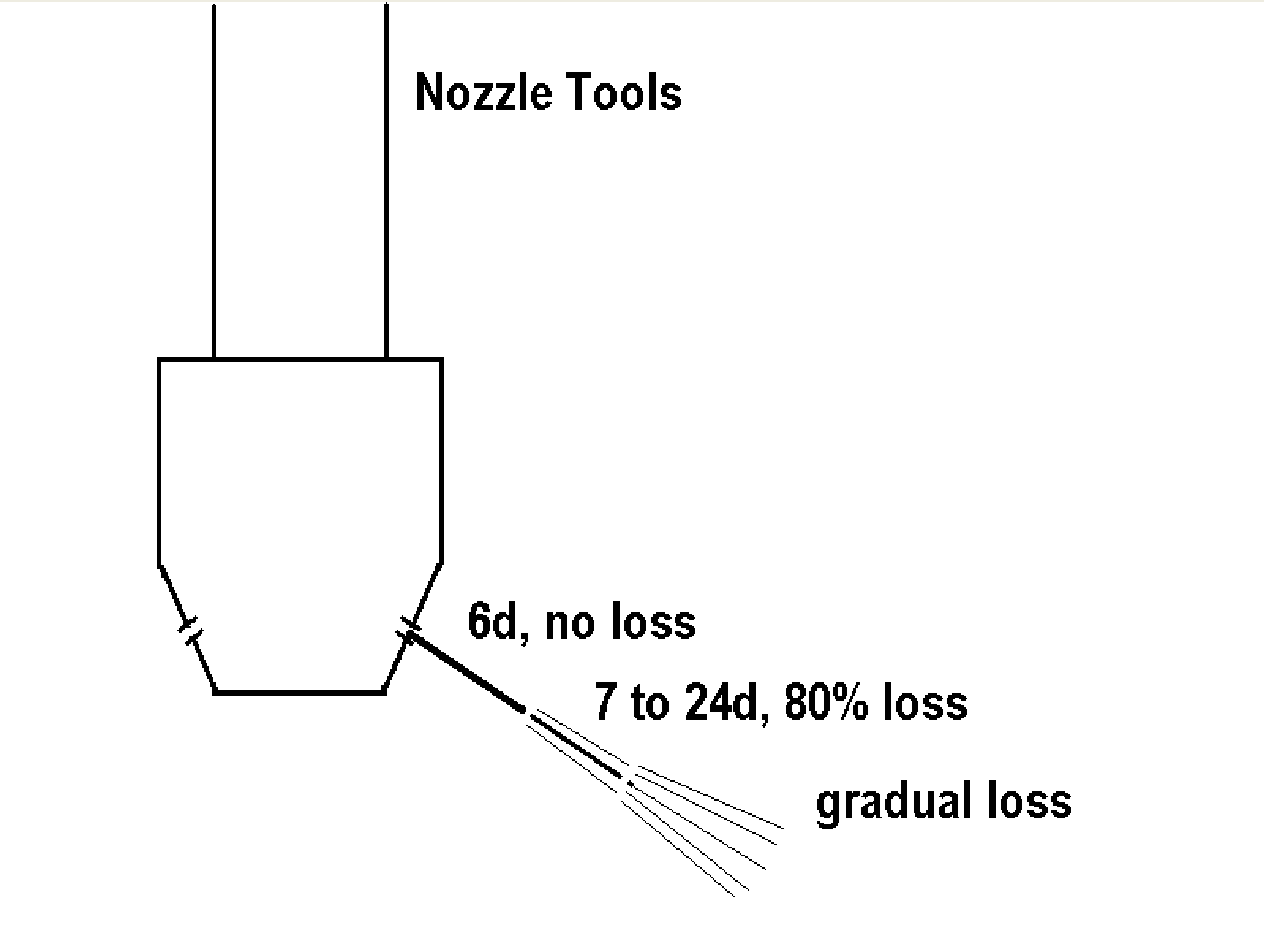




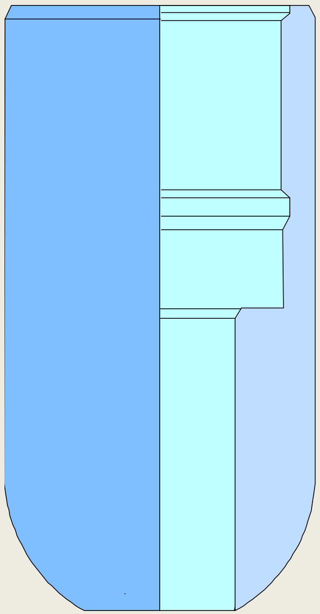


Underreamer (pumpout type)

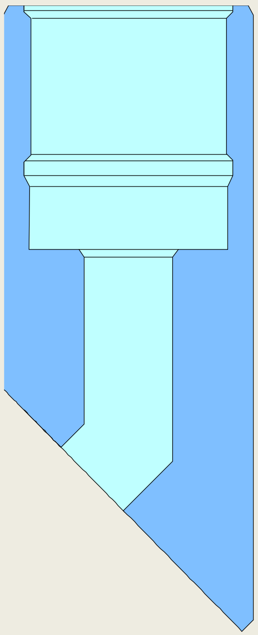

motor
cutter
anchor


Nozzle Tools
6d, no loss
7 to 24d, 80% loss
gradual loss

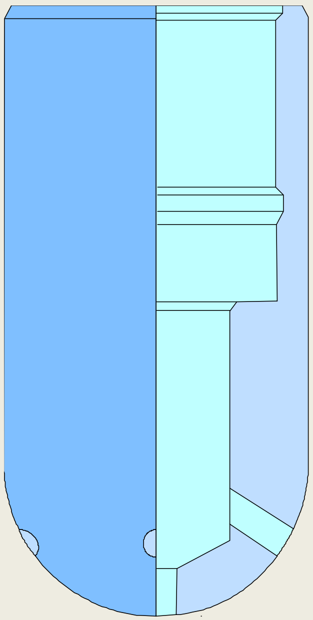
Nozzles and Jetting Subs



Single large-diameter port

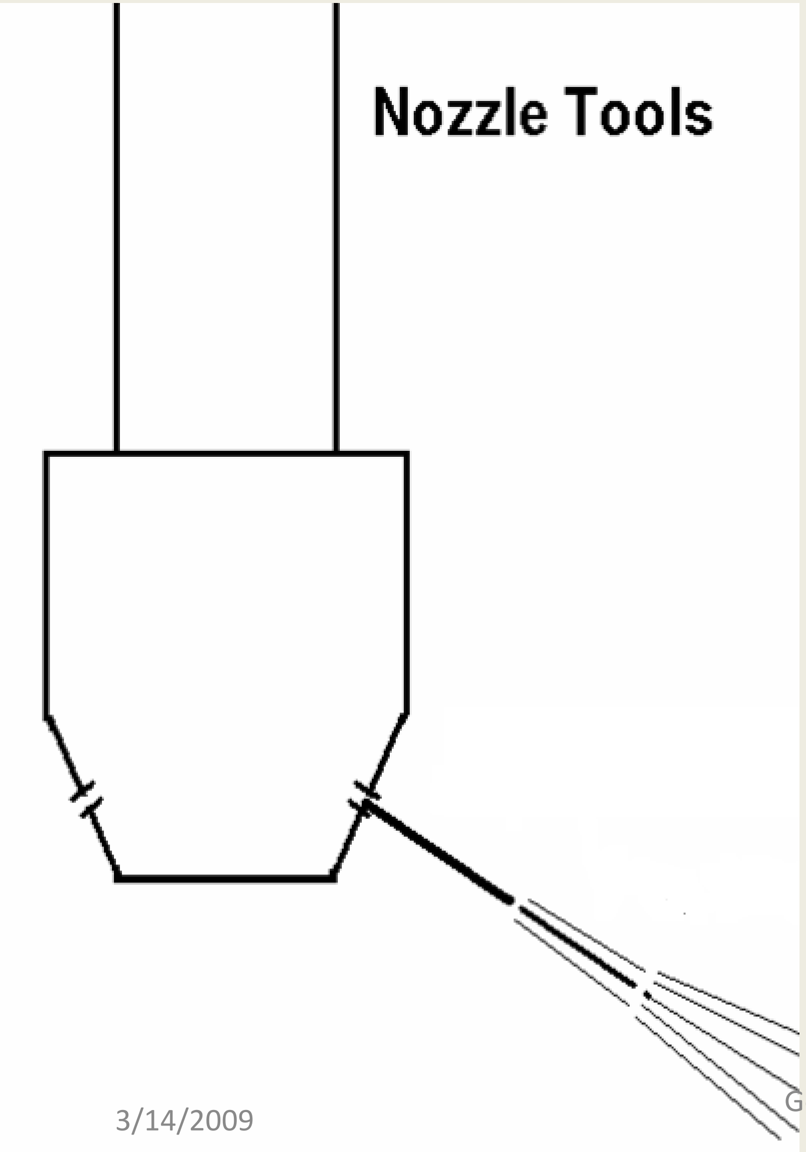


Muleshoe Angled Jet Nozzle



Multiple small-diameter ports

Water jets fan out quickly and lose impact force.



Nozzles and Jetting Subs

- Key features of nozzles and jetting subs
  - Form downhole end of CT bottomhole assembly
  - Generally of simple design and construction
  - Position and size of nozzle ports
    - determined by required jetting action
  - These tools fall into two categories
    - circulating subs
    - jetting subs
    - reversing subs

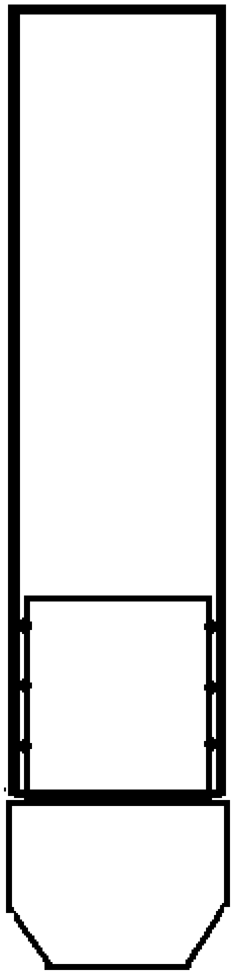
Circulating Subs

- Nozzles used where fluids circulated without a jetting action
  - Require a large port area

- Port area may be composed of
  - Several small ports to increase turbulence
  - A few large ports, with little pressure drop across nozzle

Jetting Subs

- Nozzles used where jetting action required
  - Require a small port area
  - Port area usually composed of several small ports
  - Efficiency of jetting nozzle dependent on fluid velocity through port
  - Position, shape and direction of jet ports determined by intended application
  - Combination nozzles often used to perform special operations



Pump-out Plug

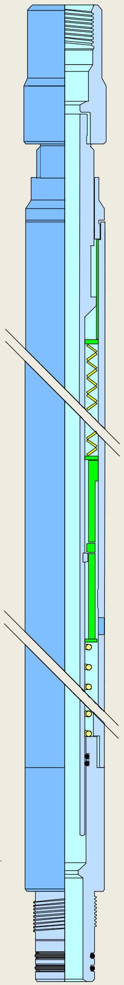
Commonly used in running CT for completions

Bowspring Centralizer – used for centralization of tools in fishing in deviated wells.

Jars

- Jars
  - Deliver sudden shock (up or down) to toolstring
  - Generally include a sliding mandrel arrangement
    - allows brief and sudden acceleration of toolstring above jar
- Most jars release in one direction only
  - Some designs can jar up and down without resetting
- If jar included in CT bottomhole assembly
  - Accelerator must also be fitted

Jars



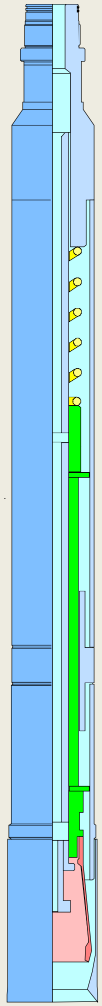
- Types of jars used in CT operations
  - Mechanical
  - Hydraulic
  - Fluid powered (e.g. impact drill)

- All three jar types operate on the upstroke

- Only mechanical or fluid powered jars capable of downstroke

-

Overshots



- Recommended that only releasable overshots are used in CT operations

- Principal features of releasable overshots
  - Catch/release mechanism
  - Bowl/grapple assembly
  - Circulation facility
    - enables circulation of fluid

Loads and Forces

- Tensile
- Burst
- Collapse
- Torsion
- Cyclic Fatigue
- Modeling

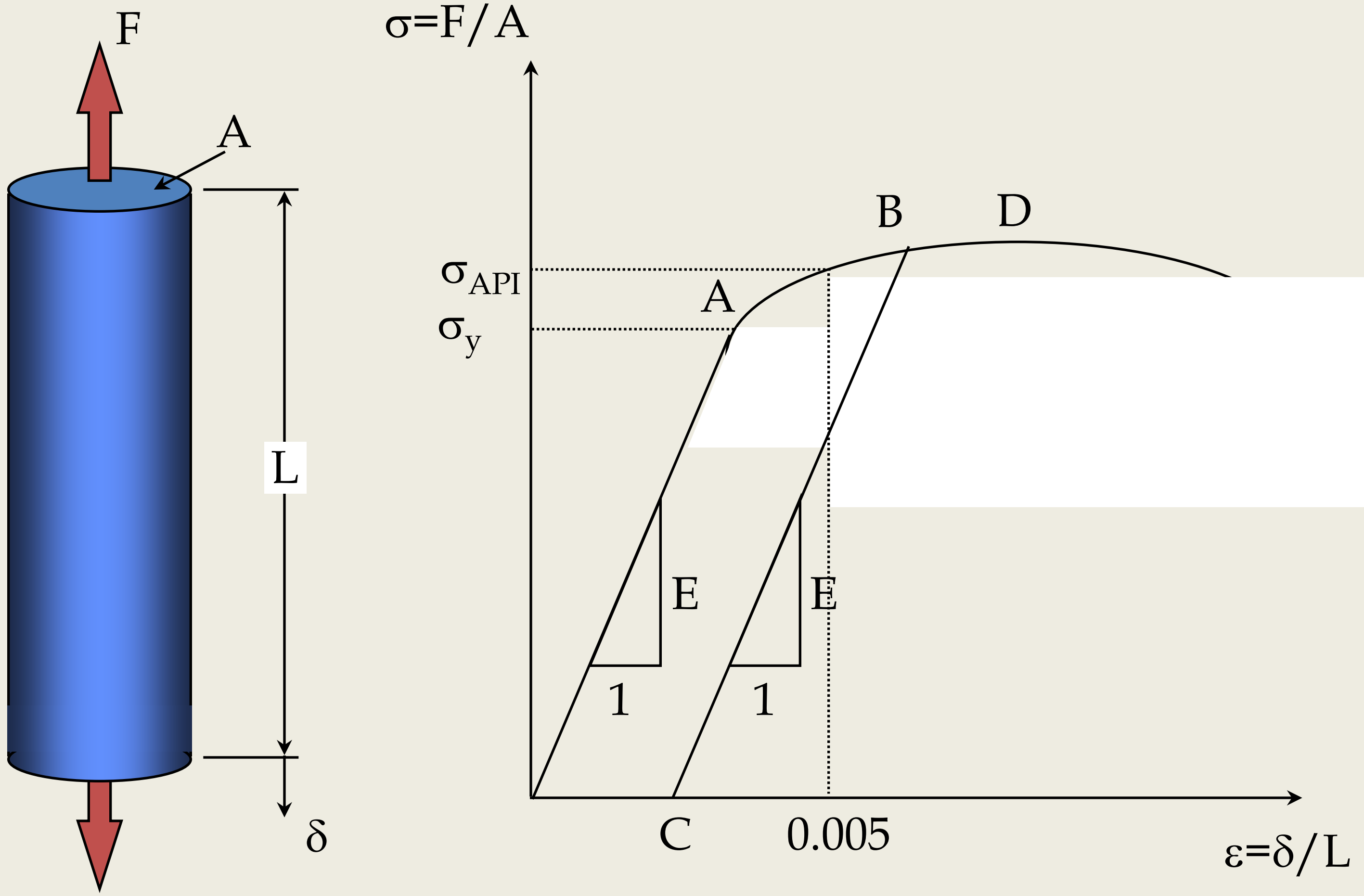
Loads

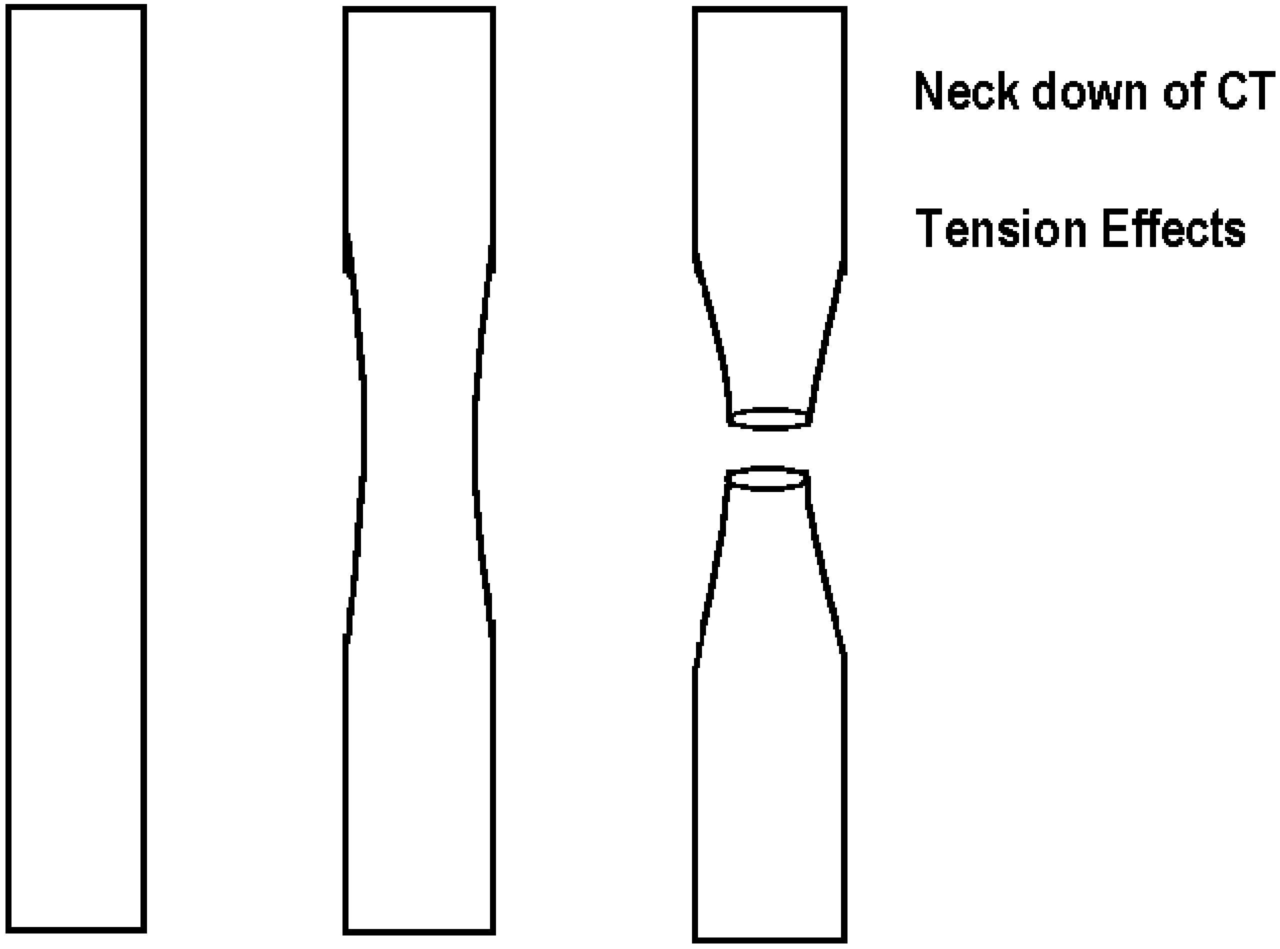
- Tensile (last section and in deep well section)
- Burst (last section and in high pressure section)
- Collapse
- Buckling (defered to deviated well section)
- Torsional (nope, not a typo)

Tension

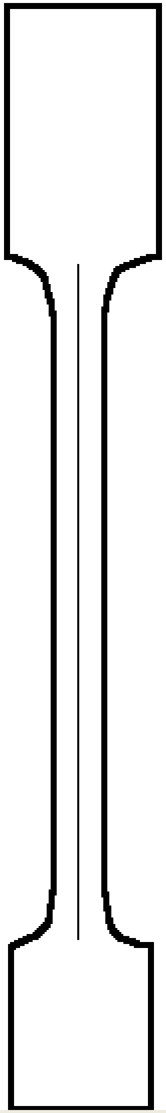
- Weight produces stretch
- Increased by BHA weights
- Increased by friction on POOH
- Offset to some degree by well fluids

Uniaxial Tension





Tension failure mode for CT in the laboratory.



Collapse more common than neck down

The collapse failure is more common in the field because of CT ovality and annular pressure reducing collapse resistance.

Axial Load Capacity

- The one-dimensional axial load capacity of the tubing is considered to be the tension load that will produce a stress in the tubing equal to the minimum yield.

$$L_y = S_y A$$

where: L_y **= CT load cap. at yield, lbs**

S_y **= yield strength of the CT, psi**

A **= x-sect. area of CT,** in^2

Load Capacity Example

- For a 1.5”, 0.109 wall CT of 70,000 psi yield strength steel, the one-dimensional load capacity at yield is:

  Ly = 70,000 psi x 0.476 in^2= 33,320 lb

  an 80% operating factor is common.....
- Ly = (0.8)*33,320 = 26,656 lb

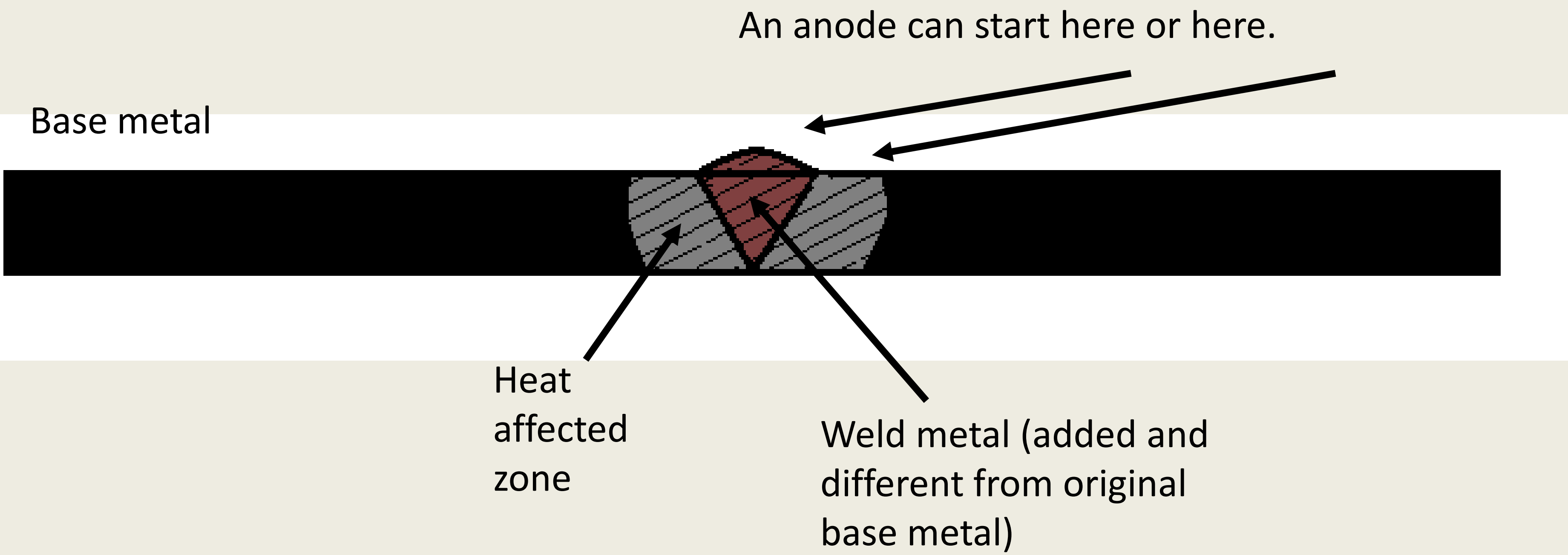
Operating Safety Factor Suggestions

- 0.8 under best conditions - new strings, especially high strength strings
- 0.5 to 0.7 for field welds
  - 0.7 for welds in lower section
  - 0.5 for welds in upper section
  - 0.5 for questionable welds
- 0.4 to 0.5 for corroded strings
  - consider refusing the string if corrosion severe
  - refuse string if <u>any</u> evidence of pin holes

Welds

The heating that occurs during the welding process will cause the weld metal and the heat affected zone around the weld to be physically different from the surrounding, original metal.

An **anode** is created by this difference.



Simplistic Depth Limits

$$L_e = L_{y(80\%)}/W$$

where:

L_e = equivalent string length

$L_{y\ (80\%)}$ = 80% of CT load capacity

W = tubing weight (effective), lbs/ft

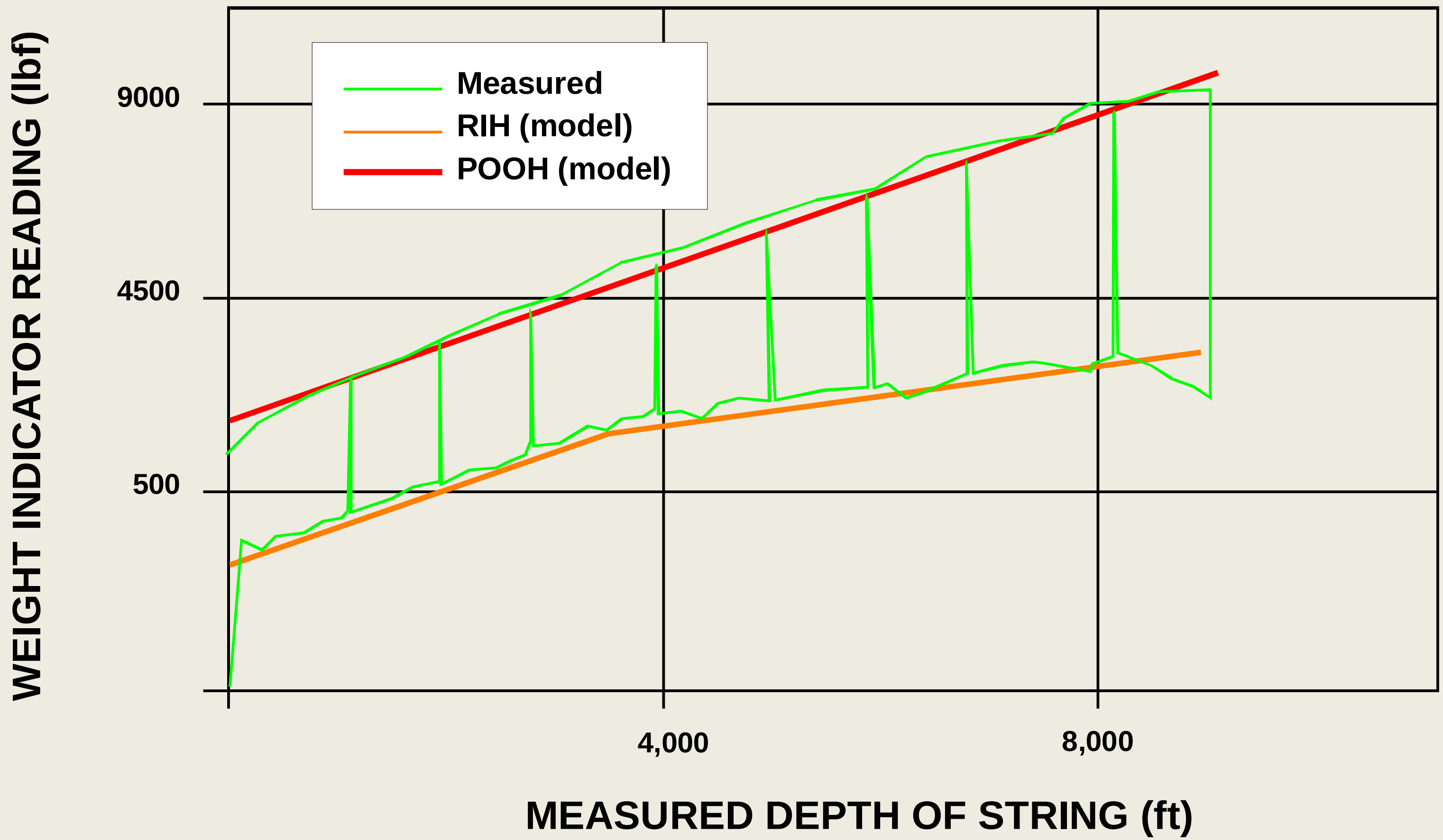
Depth Limits, without buoyancy

Examples of Depth (length) Limits of 1.5" CT (no buoyancy)					
CT OD (in)	wall (in)	weight (lb/ft)	yield strength (psi)	80% yield load (lbs)	max string length in air (ft)
1.5	0.095	1.426	70,000	23,482	16,466
1.5	0.109	1.619	70,000	26,672	16,474
1.5	0.134	1.955	70,000	32,200	16,470
1.5	0.087	1.313	100,000	30,896	23,531
1.5	0.109	1.619	100,000	38,104	23,536
1.5	0.134	1.955	100,000	46,000	23,529

Other factors that figure in….

- POOH loads are increased by:
  - frictional drag forces along walls
  - frictional drag in fluids
  - bending loads through deviated sections
  - BHA weights

Weight Indicator Load - Verification



Internal Yield Pressure (Burst)

$P_B = 2\ (t_{\text{wall-min}}) S_y / OD$

Where:

P_B = internal yield or burst pressure, psi $t_{\text{wall-min}}$ = thinnest wall, in

S_y = yield strength of the CT, psi

Burst Pressure: This one is really tricky!

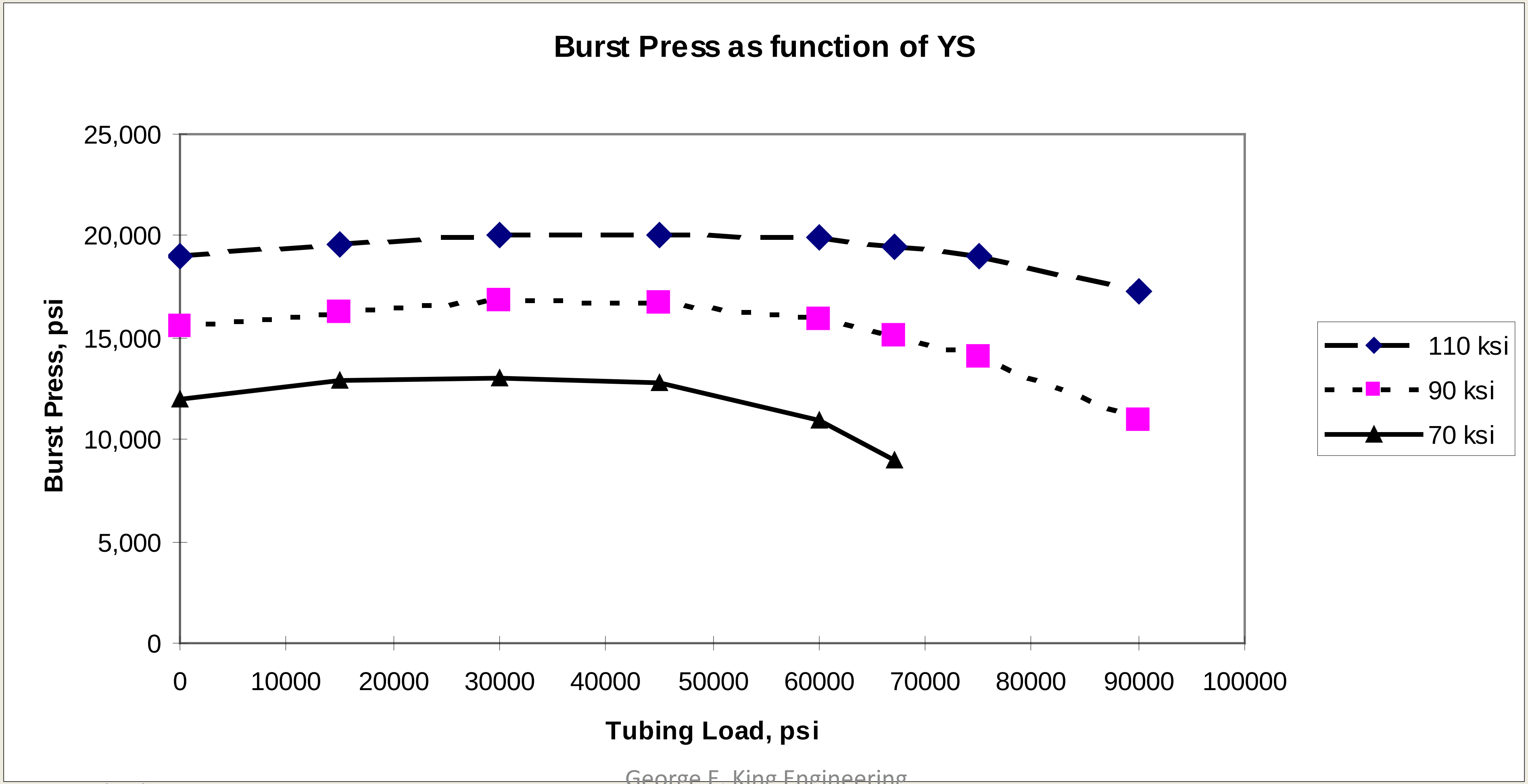
- Depends on:
  - CT size
  - CT wall thickness
  - CT strength
  - damage (dents, corrosion, ovality, fatigue)
  - offsetting pressure (it's a differential)
  - mechanical loads? - (compression? - usually not a factor)

Theoritical Burst Calc. with Round Tube				
CT OD	wall	Yield	Burst (theory)	
(in)	(in)	(psi)	(psi)	
1.25	0.095	80,000	12160	
1.25	0.095	70,000	10640	
1.25	0.075	70,000	8400	
1.25	0.125	70,000	14000	
1.25	0.156	70,000	17472	
1.25	0.151	80,000	19328	

The problem is that the tube isn’t round.

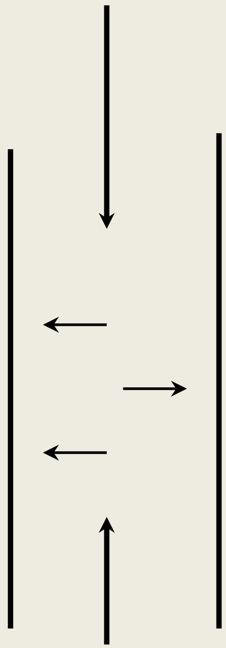
Theoritical Burst Calc. with Round Tube				
CT OD	wall	Yield	Burst (theory)	
(in)	(in)	(psi)	(psi)	
1.25	0.151	70,000	16912	
1.5	0.151	70,000	14093	
1.75	0.151	70,000	12080	
2	0.151	70,000	10570	
2.375	0.151	70,000	8901	
2.875	0.151	70,000	7353	
3.5	0.151	70,000	6040	

The Variation of Theoretical Burst ***in New, Round Pipe*** and Yield Strength with Tension Load



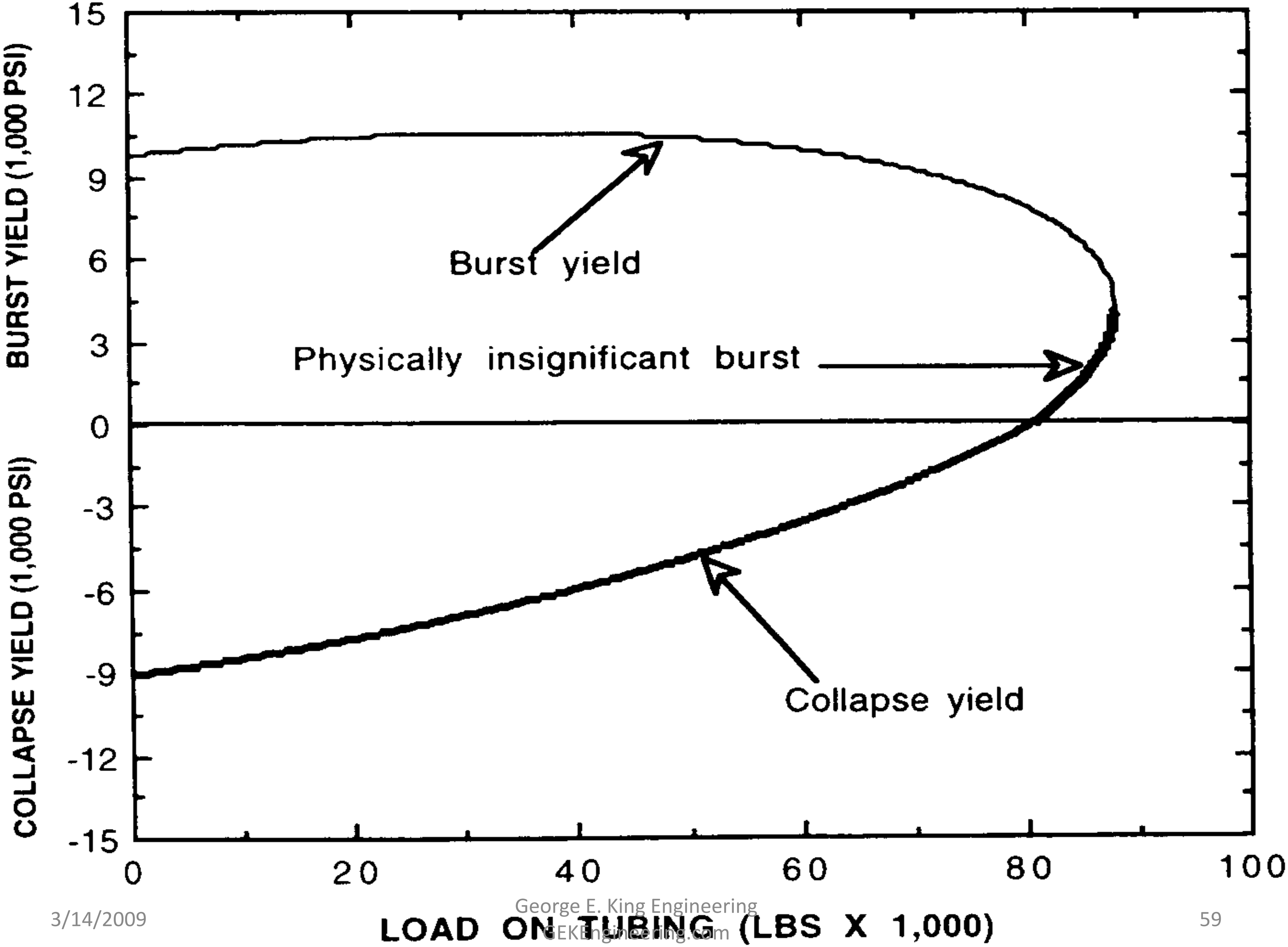
When Burst is Affected by Compression

- Loads during Snubbing (minor effect!)



Collapse Pressures

- Derated by tension
- charts are not accurate - tube not round
  - One of the biggest misrepresentations in the CT data is that of collapse pressure data.
  - Personal Opinion - use these charts as the best possible case and derate the prediction at least 30%.


15
12
9
6
3
0
-3
-6
-9
-12
-15
BURST YIELD (1,000 PSI)
COLLAPSE YIELD (1,000 PSI)
Burst yield
Physically insignificant burst
Collapse yield
0
20
40
60
80
100
LOAD ON TUBING (LBS X 1,000)

Collapse Curves

- They may not be accurate:
  - Curves do allow deration of CT collapse limits by tension
  - However, no considerations of effect of swell/ovality/damage/corrosion…
  - Derate further??? Suggest 30% if you know loads will vary.

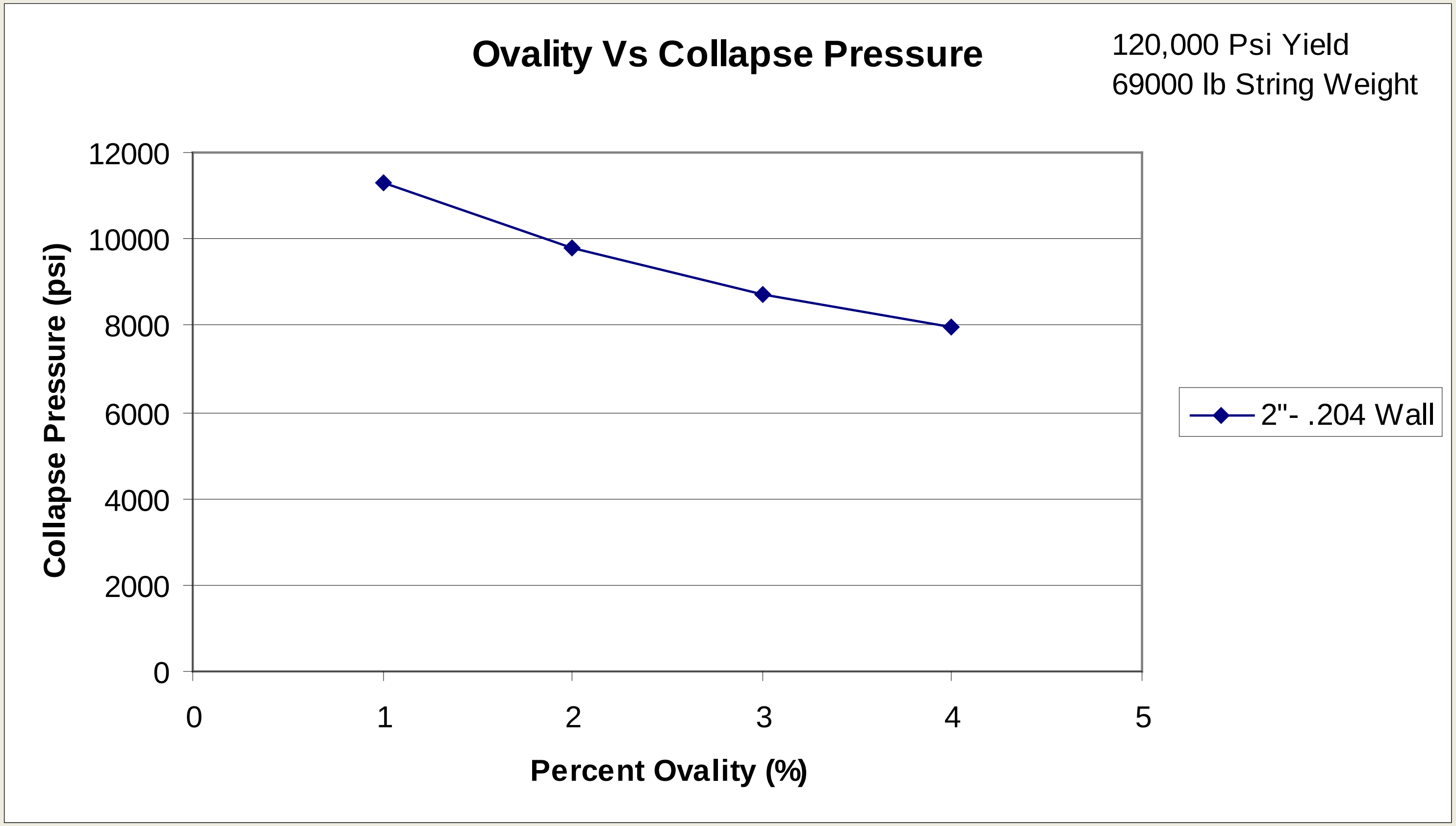
Ovality

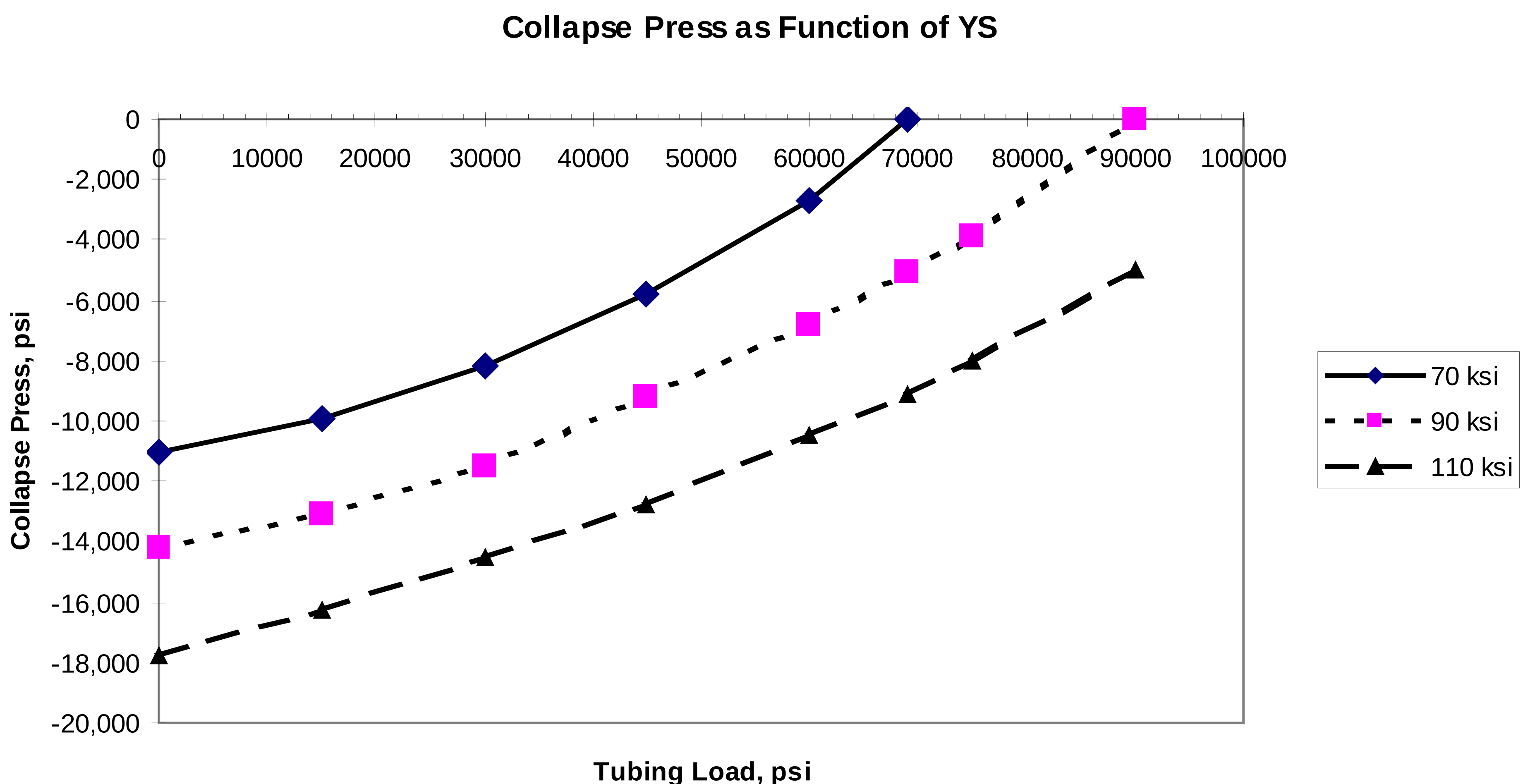
- Diameter increases most along sides and walls thin proportionally.
- Ovality creates unequal stress on CT.
- Some total diameter swell

Ovality = (OD $_{max}$ - OD $_{min}$)/OD $_{spec.}$

Solution? Measurement, Testing, Life models and, oh yeah, Experience.

COIL OVALITY



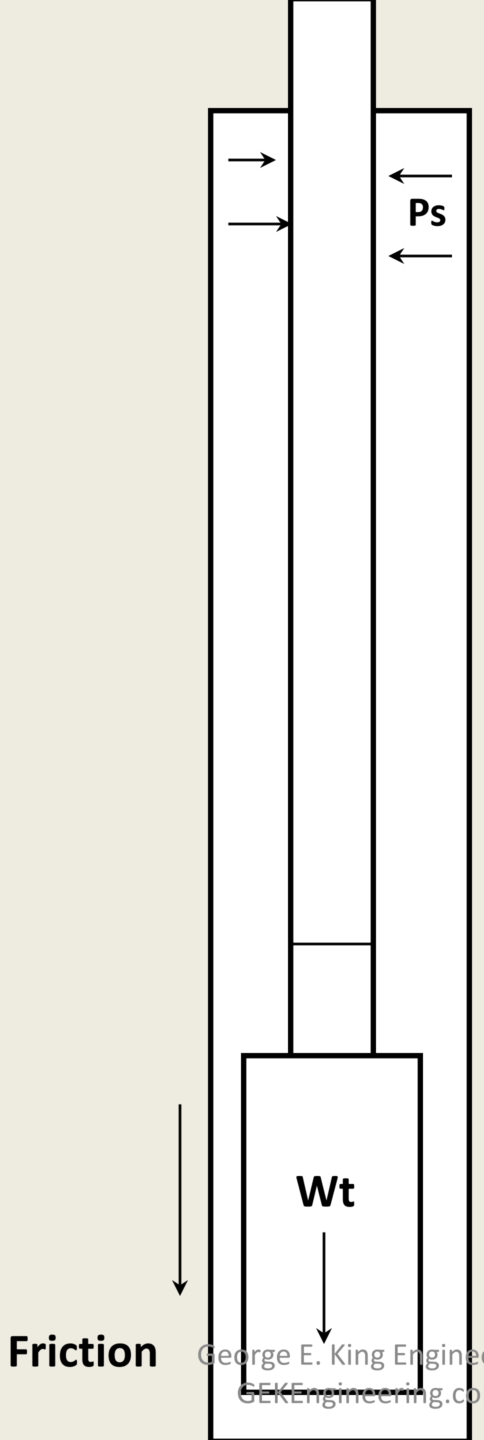

Collapse Press as Function of YS
Collapse Press, psi
Tubing Load, psi
0
-2,000
-4,000
-6,000
-8,000
-10,000
-12,000
-14,000
-16,000
-18,000
-20,000
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
70 ksi
90 ksi
110 ksi

CT Collapses

- CT collapses from a few feet to over 1100 ft have been reported. The problem is that CT is often operated right on the edge of material strength so any disturbance <u>spike</u> (sudden application of load) that can push it to collapse may trigger a collapse in several hundred feet of tube - like a run in hose.
- Remember, tensile force changes as well unloads?

Worst (?) Cases

1. High annular surface pressure
2. Long CT string
3. Heavy BHA
4. Large diameter BHA
5. Viscous annular fluids
6. Highly ovaled or damaged CT strings or sections
7. Corrosion



Most severe problem jobs for CT collapse:

1. POOH with any BHA
2. POOH through severe dogleg
3. Fishing (and jar action)
4. Trying to free stuck tubing

Collapse

- Variables
  - Strength of CT
  - Condition of the CT - big variances
  - Ovality of CT
  - Size of CT
  - Damage (corrosion, wear, ovality, dents, etc)
  - External pressure (pressure differential)
  - Axial load

Collapse Summary

- Changing variables = moving target. Watch the balance of surface pressure, friction and load. All of these change during the job.
- Sudden application of load more likely to promote CT collapse than a steady pull
- Collapse curve accuracy?? Only for round tubes - CT isn't.

Accuracy Problems

- For any ***constant*** shape and size piece of pipe, an expression or method of prediction for tension, collapse, or burst can be generated. <u>BUT, CT is a reel of variences handled by a system of extremes.</u> The <u>***best***</u> we can do are estimations.

Torsion Yield Strength

$T_y = S_y(OD^4 - (OD - 2\ t_{wall\text{-}min})^4)/105.86\ OD$

Where:

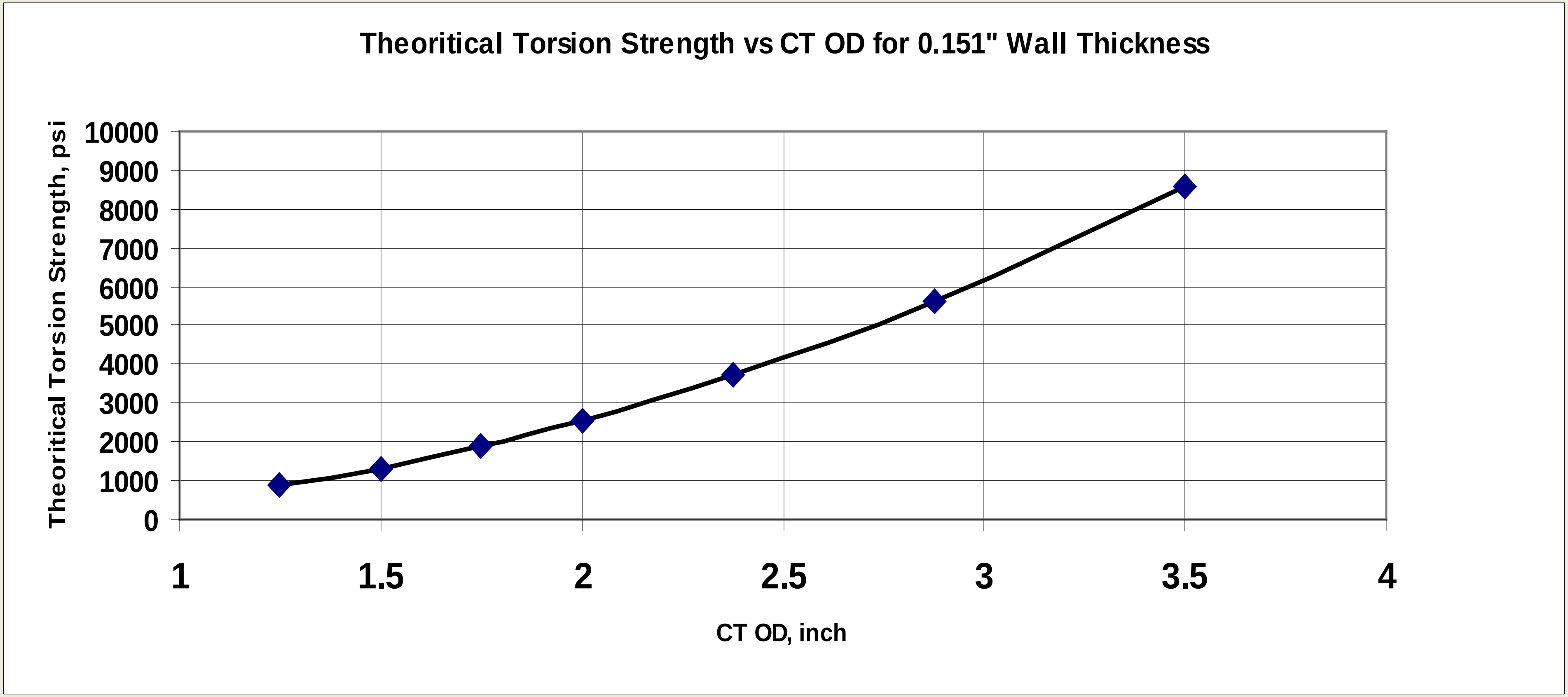
T_y = Torsion Yield Strength, lb-ft

$t_{wall\text{-}min}$ = thinnest wall, in

S_y = yield strength of the CT, psi

OD = CT OD

Torsion Strength for CT
Why bother with torsion for CT?



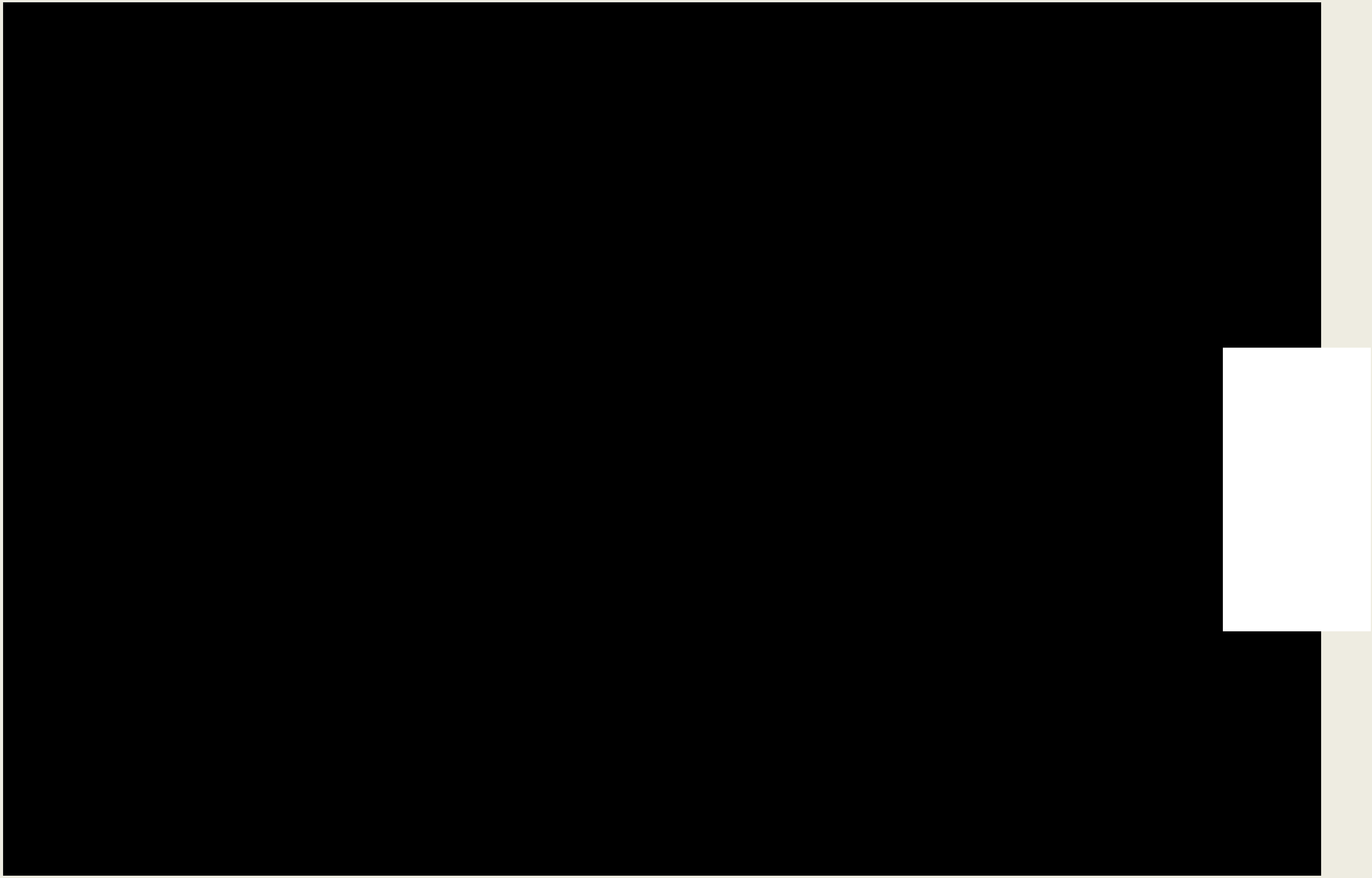
Torque

- Usually we don’t push the torque limit in workovers
  - need to rotate is very limited
  - smaller motors are very limited in torque output
- This changes in CT Drilling, especially with big motors

TheoriticalTorque Calc. with Round Tube				
CT OD	wall	Yield	Torque (theory)	
(in)	(in)	(psi)	(psi)	
1.25	0.07	70,000	488	
1.25	0.151	70,000	864	
1.5	0.151	70,000	1324	
1.75	0.151	70,000	1883	
2	0.109	70,000	1956	
2	0.151	70,000	2542	
2.375	0.151	70,000	3717	
2.875	0.151	70,000	5633	
3.5	0.151	70,000	8590	

Fillup

- Volumes vary with OD and wall thickness
- Remember, the volume of CT is not just what’s in the well - it includes what’s on the reel.
- Friction can be a killer when rates are needed - **remember: reel + well**.



Force Application on CT

- Force to push CT through stuffing box/stripper (opposite running)
- Force on CT from Well Head Pressures - (upward)
- Force to overcome friction (opposite running)
- Force from weight of CT & BHA (downward)

Other Forces and Loads

- Pressure Effects on Length/Force
- Temperature Effects on Length/Force
- Stretch
- Buckling loads

Swab/Surge Forces

- “Plunger force” - tremendous force exerted event in small movements because of large area affected.
- Close clearances and high tool movement speeds increase the swab/surge force
- Circulation while pulling lessens swab/surge loads

Swab Forces

- Problems
  - small hole volumes
    - **small gas influx causes large underbalance - get in trouble quickly**
  - large BHAs - swab force increased sharply
  - continuous, fast movement of CT
  - horizontal holes
    - **gas storage area - isn't apparent on surface gauge quickly - must monitor trip tanks.**

Swab Effect From Pipe Speed

Hole Size, in.	Pipe pulling Speed, fpm			
	360	245	180	120
8.5	276	167	124	98
6.5	589	344	256	192
5.75	921	524	394	289

14 lb/gal mud, 4.5" BHA

Adams

CT Swab and Surge Pressure Effects at BH

- Extreme, short duration pressure spikes at BH during CT movement
- Stick/slip cause????
- Aggravated by big/heavy BHA, rough holes

Could spot with a trip tank

CT Stretch - W/Buoyancy Effect

$S_{elastic}$ = 12 L $F_{bouyancy}$ / A E

Where:

- **$S_{elastic}$= elastic stretch of CT per 1000', in.**
- **$F_{bouyancy}$ = corrected pull on tubing, lb**
- **L = tube length (where load applied), ft**
- **A = cross sectional area of tubing**
- **E = modulus = 30 x 10^6 psi**

Stretch Example for 5000 ft CT With and Without Load										
					Fluid			Added	CT	CT
			Weight	Length	Density	Air Wt.	Bouyed	Load	Stretch	Stretch
CT OD	Wall, in	Area, in^2	lb/ft	(ft)	(lb/gal	(lbs)	Wt, (lbs)	(lbs)	inches	ft
1.25	0.109	0.391	1.33	5000	1.9	6640	6447	0	33.0	2.75
1.25	0.109	0.391	1.33	5000	1.9	6640	6447	500	35.5	2.96
1.25	0.109	0.391	1.33	5000	8.33	6640	5794	0	29.6	2.47
1.25	0.109	0.391	1.33	5000	8.33	6640	5794	500	32.2	2.68
1.25	0.109	0.391	1.33	5000	10	6640	5625	0	28.8	2.40
1.25	0.109	0.391	1.33	5000	10	6640	5625	500	31.3	2.61
1.25	0.109	0.391	1.33	5000	12	6640	5422	0	27.7	2.31
1.25	0.109	0.391	1.33	5000	12	6640	5422	500	30.3	2.52

Stretch Example for 5000 ft CT With and Without Load										
					Fluid			Added	CT	CT
			Weight	Length	Density	Air Wt.	Bouyed	Load	Stretch	Stretch
CT OD	Wall, in	Area, in^2	lb/ft	(ft)	(lb/gal	(lbs)	Wt, (lbs)	(lbs)	inches	ft
1.5	0.109	0.476	1.62	5000	1.9	8095	7860	0	33.0	2.75
1.5	0.109	0.476	1.62	5000	1.9	8095	7860	500	35.1	2.93
1.5	0.109	0.476	1.62	5000	8.33	8095	7064	0	29.7	2.47
1.5	0.109	0.476	1.62	5000	8.33	8095	7064	500	31.8	2.65
1.5	0.109	0.476	1.62	5000	10	8095	6857	0	28.8	2.40
1.5	0.109	0.476	1.62	5000	10	8095	6857	500	30.9	2.58
1.5	0.109	0.476	1.62	5000	12	8095	6610	0	27.8	2.31
1.5	0.109	0.476	1.62	5000	12	8095	6610	500	29.9	2.49

Stretch Example for 5000 ft CT With and Without Load										
					Fluid			Added	CT	CT
			Weight	Length	Density	Air Wt.	Bouyed	Load	Stretch	Stretch
CT OD	Wall, in	Area, in^2	lb/ft	(ft)	(lb/gal	(lbs)	Wt, (lbs)	(lbs)	inches	ft
2	0.109	0.648	2.20	5000	1.9	11005	10685	0	33.0	2.75
2	0.109	0.648	2.20	5000	1.9	11005	10685	500	34.5	2.88
2	0.109	0.648	2.20	5000	8.33	11005	9603	0	29.6	2.47
2	0.109	0.648	2.20	5000	8.33	11005	9603	500	31.2	2.60
2	0.109	0.648	2.20	5000	10	11005	9322	0	28.8	2.40
2	0.109	0.648	2.20	5000	10	11005	9322	500	30.3	2.53
2	0.109	0.648	2.20	5000	12	11005	8986	0	27.7	2.31
2	0.109	0.648	2.20	5000	12	11005	8986	500	29.3	2.44

CT in Horizontals and Multi-laterals

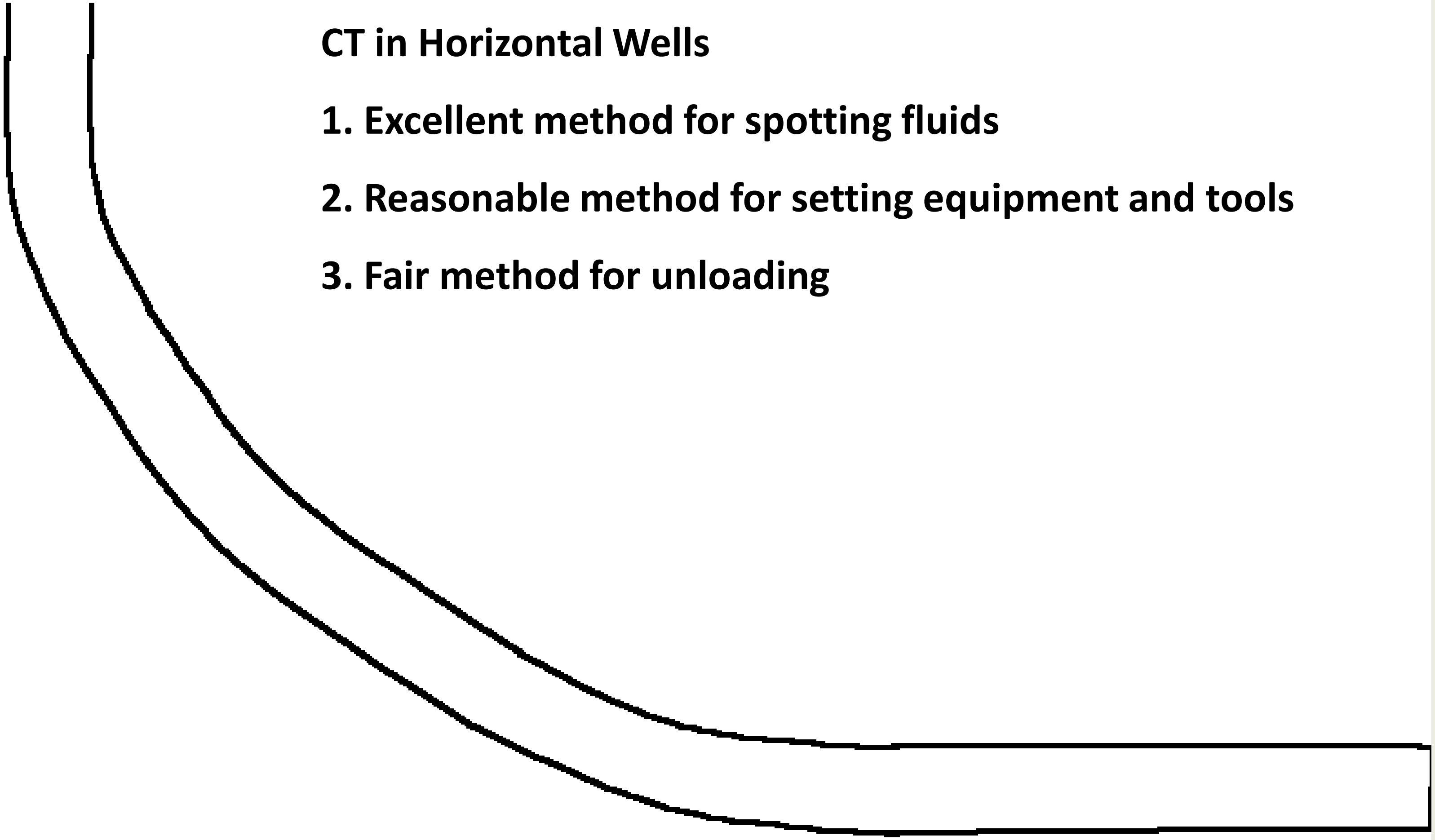
- Buckling loads and estimation of reach
- Methods of extending reach
- Examples of CT use

CT in Horizontal Wells

1. Excellent method for spotting fluids

2. Reasonable method for setting equipment and tools

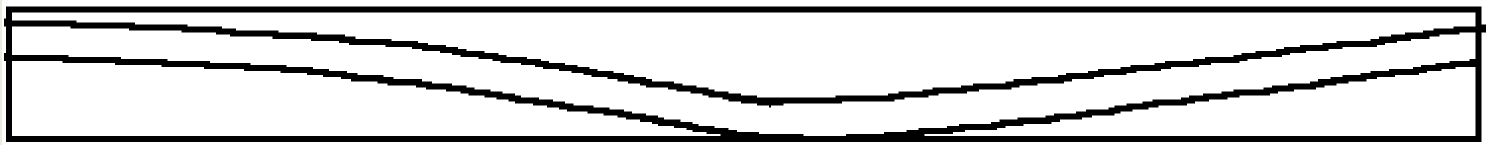
3. Fair method for unloading



Sticking Points

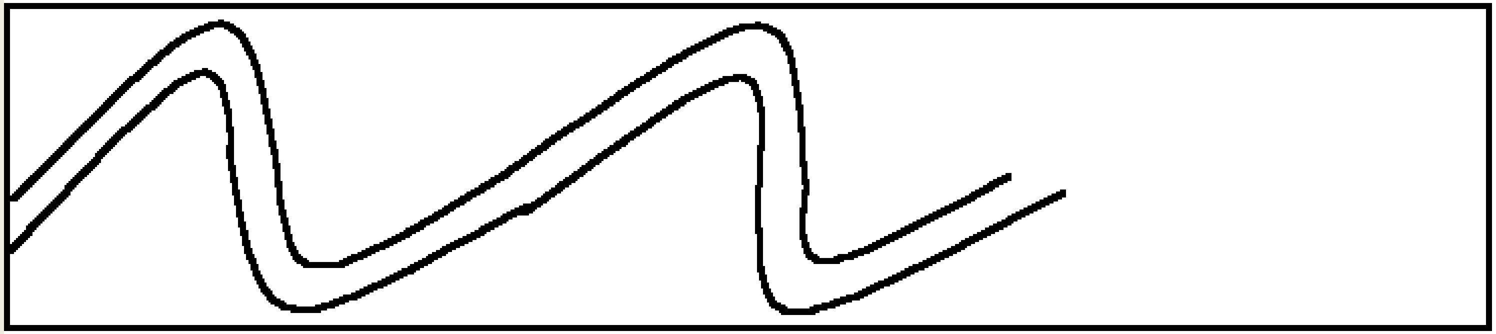
1. Bend area

2. Lateral



Sinusodial Buckling - limited wall drag & some deflection at the wall

Helical Buckling - (like the spring in a ball point pen) - maximizes wall drag and stops pipe movement. Most common with small pipe in a large hole.



Max tool length through the bend area….

Max length of stiff pipe or tool…

$L=1/6[R^2 - (R - {}^\wedge d)^2]^{1/2}$

where:

L = tool length, ft

R = curve radius, inches

^d = ID casing - OD tool (inches)