

Recent Casing Failures in Horizontal Wells

- For the meeting of AADE membership Denver
- May 14, 2013
- At the Denver Athletic Club
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RECENT CASING FAILURES IN HORIZONTAL WELLS

- Mills hesitate to discuss problems publicly
 - Reputation – customers, competitors
 - Avoid legal actions
 - Respect customer privacy
- Operators hesitate to discuss problems publicly
 - Reputation – partners, investors, competitors

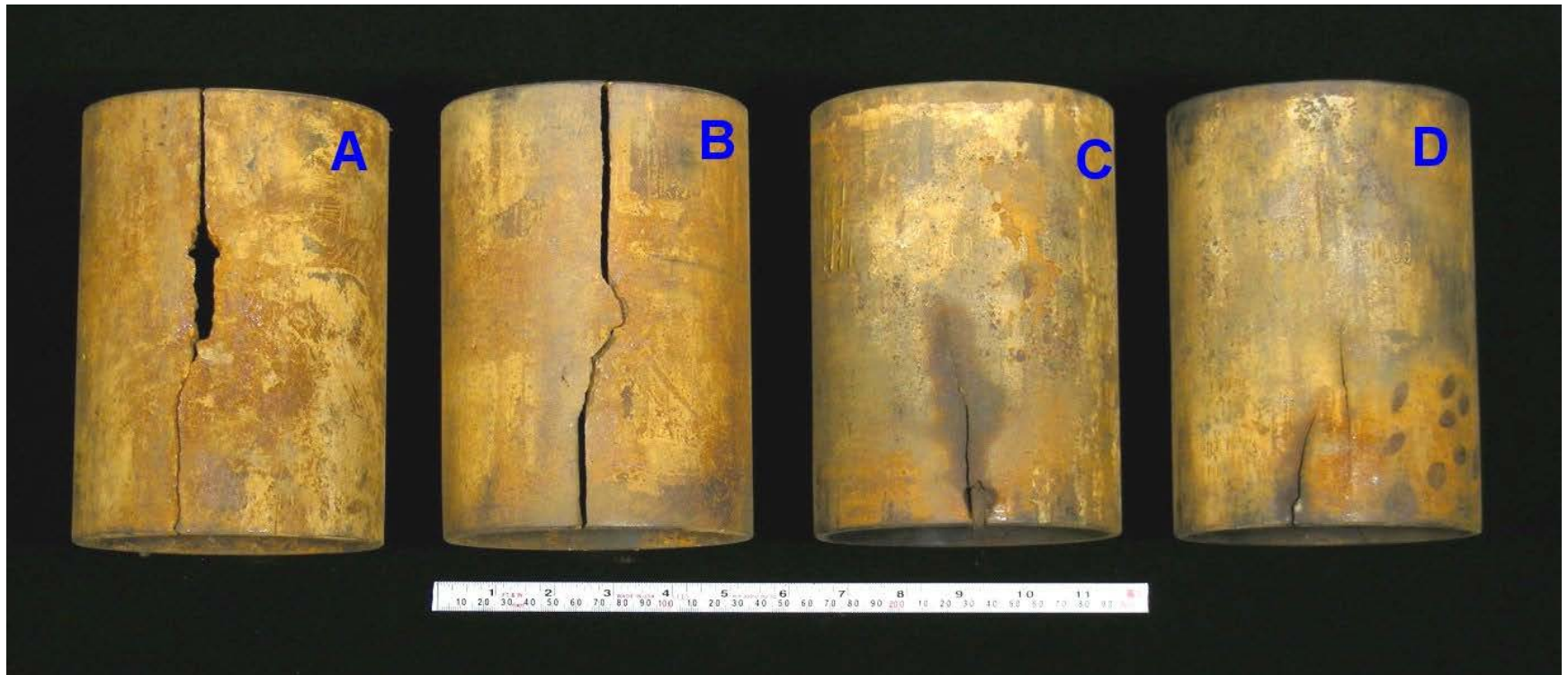
Casing Failure Cases

1. Coupling failures in P-110 casing/coupling
2. Split failures near heel after multiple frac jobs
3. Jewelry failures in lateral
4. Vibrations in wellhead, pin fatigue failure
5. Poor joint strength in casing near surface

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments



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- Couplings can be located anywhere in string
- Coupling experiences a longitudinal split
- Time of failure is usually after cementing to during frac job
- No evidence of abuse or improper makeup
- Often cause to abort a frac stage
- Can be associated with trace amount of H_2S , but H_2S not required

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

- Some operators are pushing “trace” H_2S beyond reasonable upper limit for P-110
- “Trace” defined as less than 0.05 psia partial pressure, P_{H_2S} (per NACE MR0175)
- $\rightarrow P_{H_2S} = \frac{(BHP)(H_2S \text{ concentration, ppm})}{1,000,000}$
- Example: $BHP = 3000 \text{ psi}$, $H_2S = 20 \text{ ppm}$
- $\rightarrow P_{H_2S} = \frac{3000 \times 20}{1,000,000} = 0.06 \text{ psi}$
- $0.06 > 0.05, \therefore$ sour, P-110 not appropriate

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

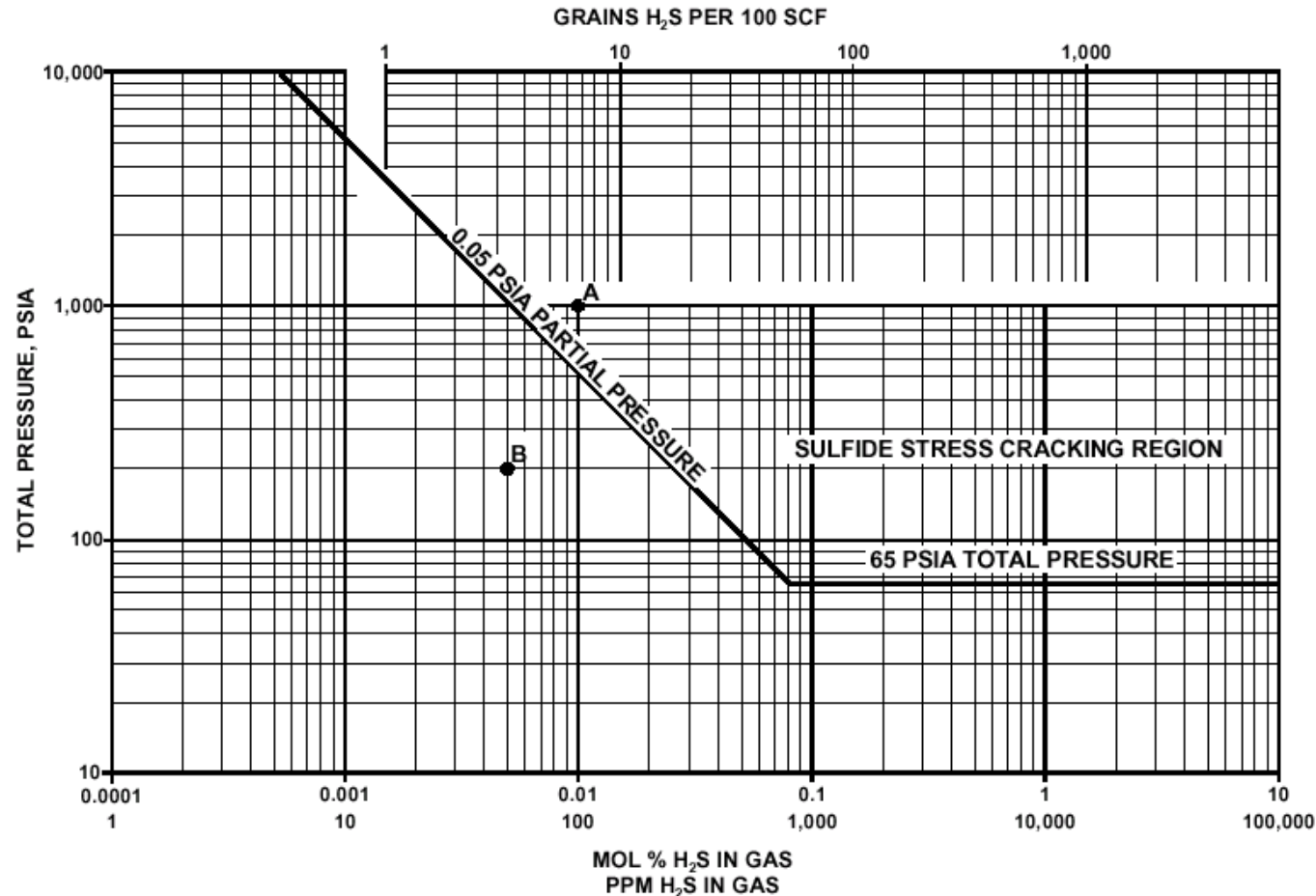


Table from NACE MR0175

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

- Material aspects
 - High yield strength P-110 material
 - Hardness exceeds certain limits

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

- The Probability of SSC Embrittlement Increases with:
 - Increasing H₂S Partial Pressure
 - Increasing Steel Strength and Hardness
 - Increasing Tensile Stress – Tensile stress is high in a coupling due to high hoop stress
 - Increasing Exposure Duration
 - Decreasing Percent Martensite
 - Decreasing pH
 - Decreasing Temperature

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

- High yield strength (YS) P-110 material
 - API allows YS to vary: 110 to 140 ksi
(Per API Specification 5CT)
 - 133 ksi appears to be a practical limit to YS
 - YS beyond 133 ksi very susceptible to environmentally assisted cracking in service
 - Imposing coupling YS limit on mills requires special purchasing procedures
 - Purchasing material “as rolled” is discouraged

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

Table E.6—Tensile and hardness requirements

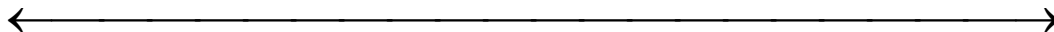
Group	Grade	Type	Total elongation under load %	Yield strength ksi		Tensile strength min. ksi	Hardness ^a		Specified wall thickness in	Allowable hardness variation ^b HRC
				min.	max.		HRC	HBW/HBS		
1	2	3	4	5	6	7	8	9	10	11
1	H40		0.5	40	80	60				
	J55		0.5	55	80	75				
	K55		0.5	55	80	95				
	N80	1	0.5	80	110	100				
	N80	Q	0.5	80	110	100				
2	M65		0.5	65	85	85	22	235		
	L80	1	0.5	80	95	95	23	241		
	L80	9Cr	0.5	80	95	95	23	241		
	L80	13Cr	0.5	80	95	95	23	241		
	C90	1, 2	0.5	90	105	100	25.4	255	≤ 0.500	3.0
	C90	1, 2	0.5	90	105	100	25.4	255	0.501 to 0.749	4.0
	C90	1, 2	0.5	90	105	100	25.4	255	0.750 to 0.999	5.0
	C90	1, 2	0.5	90	105	100	25.4	255	≥ 1.000	6.0
	C95		0.5	95	110	105				
	T95	1, 2	0.5	95	110	105	25.4	255	≤ 0.500	3.0
	T95	1, 2	0.5	95	110	105	25.4	255	0.500 to 0.749	4.0
	T95	1, 2	0.5	95	110	105	25.4	255	0.750 to 0.999	5.0
	T95	1, 2	0.5	95	110	105	25.4	255	≥ 1.000	6.0
3	P110		0.6	110	140	125				
4	Q125		0.65	125	150	135	b		≤ 0.500	3.0
	Q125		0.65	125	150	135	b		0.500 to 0.749	4.0
	Q125		0.65	125	150	135	b		≥ 0.750	5.0

^a In case of dispute, laboratory Rockwell C hardness testing shall be used as the referee method.

^b No hardness limits are specified, but the maximum variation is restricted as a manufacturing control in accordance with 7.8 and 7.9

1. Casing coupling failures in P-110 casing, horizontal, multi-frac environments

- Hardness exceeds certain limits
 - As yield strength increases, hardness increases
 - Rockwell (HRC) 30 to 31 appears to be a limit
 - L-80 Rockwell limit is 23 (for comparison)
 - API imposes no limits on hardness for P-110
 - Imposing hardness limit on mills requires special purchasing procedures
 - Purchasing material “as rolled” is discouraged



2. Split failures near heel after multiple frac jobs

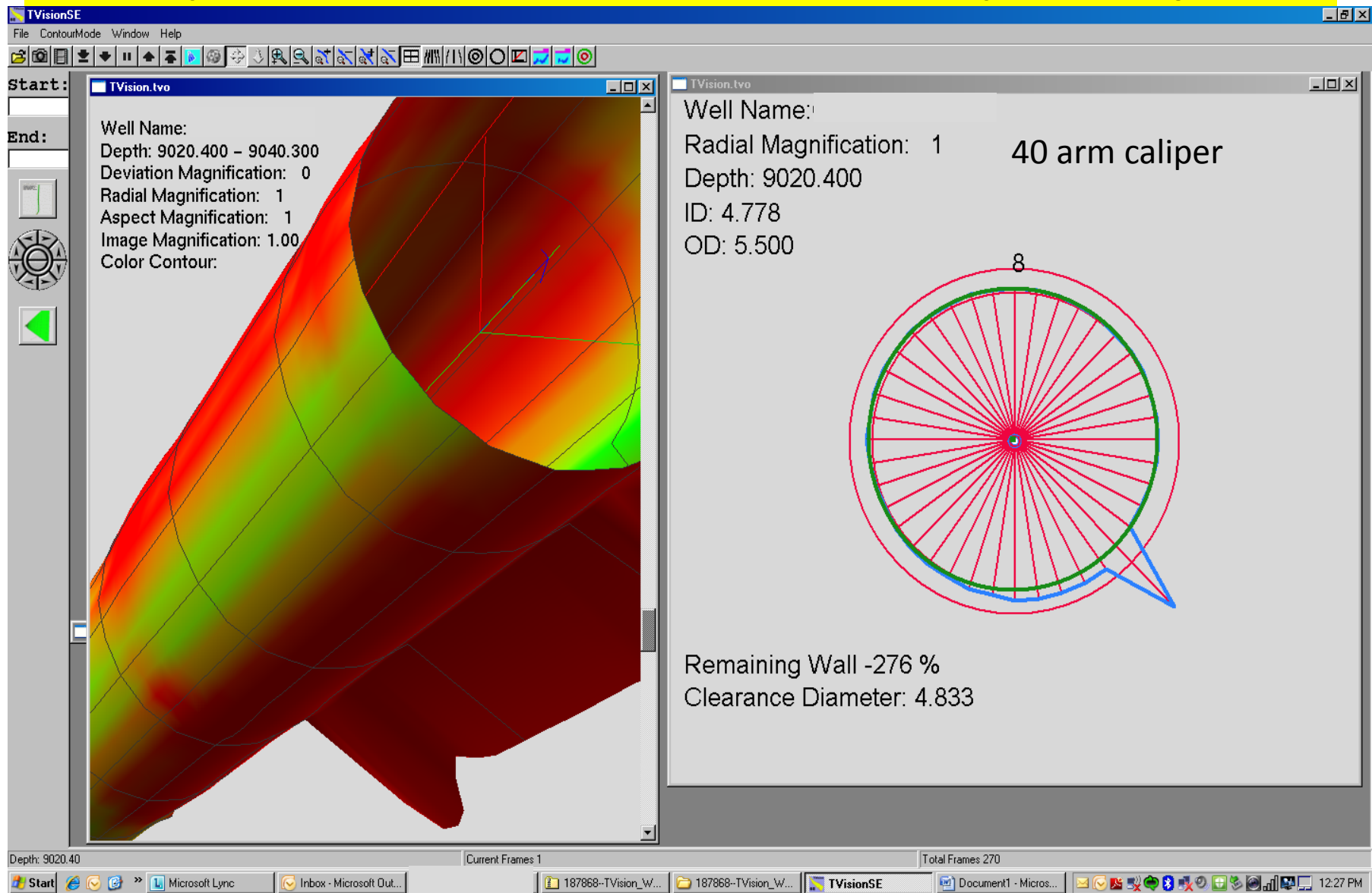


No samples recovered – Failure point located below cement top

2. Split failures near heel after multiple frac jobs



2. Split failures near heel after multiple frac jobs



2. Split failures near heel after multiple frac jobs

- Wellbore conditions
 - Usually occurs after multiple frac treatments
 - Usually in the horizontal near the heel
 - P-110 material – not L-80 material
 - Water/sand fracs, spearhead w/ HCl acid
 - Wells have not been flowed back or produced
 - High pressure, high rate fracs

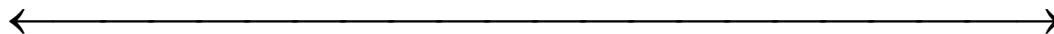
2. Split failures near heel after multiple frac jobs

- Diagnosis
 - Appears to be related to P-110 properties
 - Acid can cause sulfide stress cracking (SSC) in P-110 material
 - Repeated exposure to HCl acid can allow atomic hydrogen to be absorbed by the steel.
 - Exposure accompanied by lower temperature and high pressure.
 - High yield strength/hardness appears to be make the pipe vulnerable to embrittlement/failure.

2. Split failures near heel after multiple frac jobs

- Mitigation

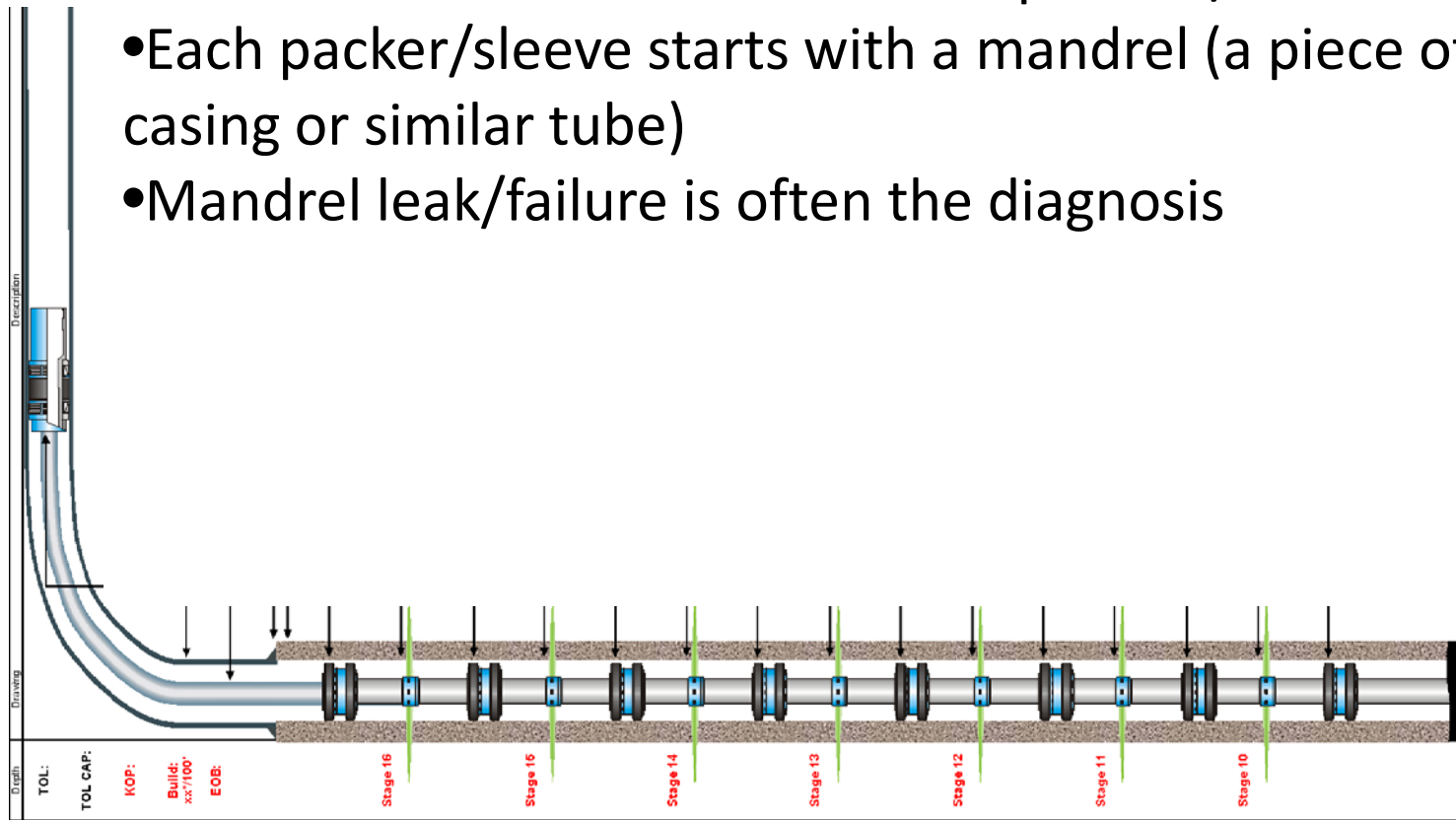
- If H_2S content is too high, P-110 grade not appropriate in the well
- Buehler suggests 133 ksi yield strength is an absolute limit for P-110, tube or coupling
- Rockwell 30-31 (depending on source) appears to be a hardness limit, tube or coupling
- Establishing these limits requires special purchasing procedures
- Pipe mills are aware of the problem
- Reputable mills are proactively addressing the problem



3. Jewelry failures in lateral

Well conditions

- Multiple packers and sliding sleeves - 16 sleeves here
- Leak failures have occurred in the packers/sleeves
- Each packer/sleeve starts with a mandrel (a piece of casing or similar tube)
- Mandrel leak/failure is often the diagnosis

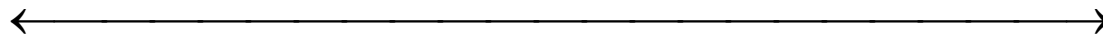


3. Jewelry failures in lateral

- Diagnosis
 - Possible product design issue – machined mandrel weaker in burst than undisturbed tube
 - More likely: Mandrel metallurgy/heat treat makes the tube subject to same types of failure as 1. & 2.
 - MTR's for mandrel material perhaps do not exist in vendor system
 - Vendor perhaps not buying quality mandrels

3. Jewelry failures in lateral

- Mitigation
 - If product design issue – make realistic rating calculations
 - Vendor must improve mandrel purchasing procedures / tracking capability
 - Use vendors who can defend quality of mandrels
 - If all fails: Quit using jewelry, fully cement liner and perforate each interval



4. Vibrations in wellhead



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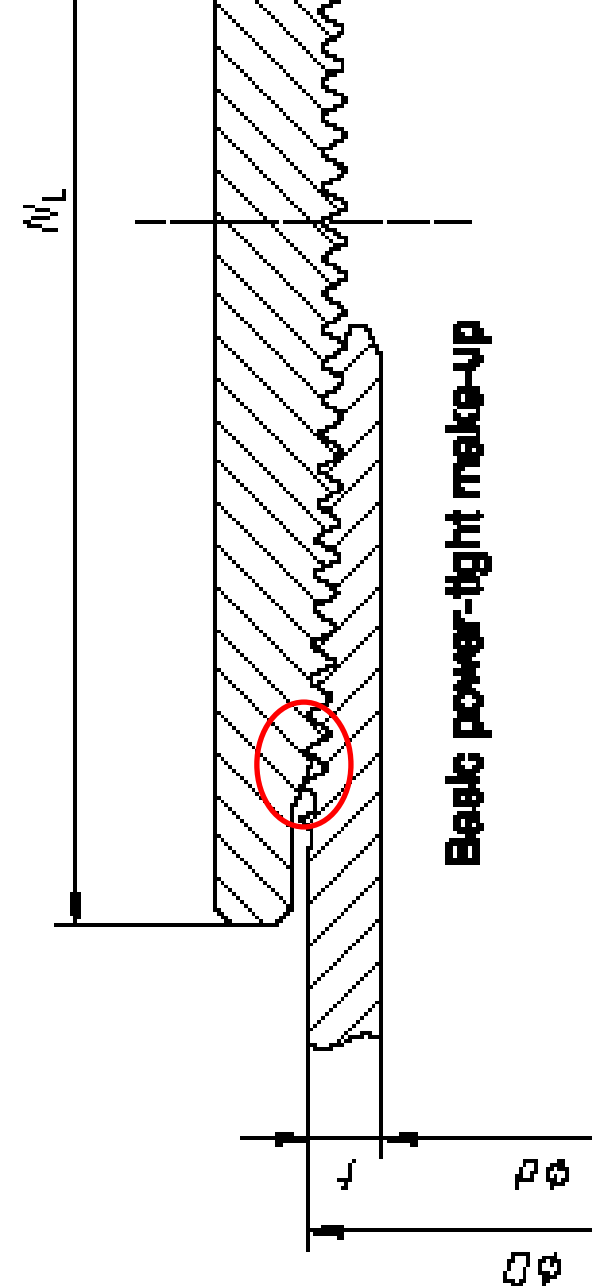
- Situation
 - Well completed with “Larkin” style wellheads
 - Casing head removed and frac head installed for frac job
 - Casing started leaking “through casing wall” during frac job
 - Job aborted, uncontrolled release of well fluids
- Diagnosis
 - Crack in casing wall at last engaged thread of frac head
 - Vibration induced crack - fatigue

4. Vibrations in wellhead



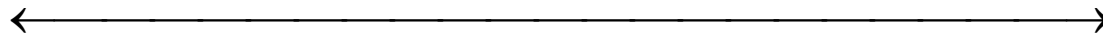
4. Vibrations in wellhead

- Diagnosis (continued)
 - Pressure/rate pulsations from pumps cause lines to cycle back and forth
 - Frac tree rocks back and forth
 - Reverse bending cycles in thin wall casing. Low cycle fatigue crack initiated at thread root (notch).



4. Vibrations in wellhead

- Mitigation
 - Isolate pump surges from wellhead/frac tree
 - Especially critical where “Larkin” style wellhead equipment is used
 - Use sufficient swings in Chiksan to isolate frac tree from long pulsing lengths of pipe
 - Chain frac tree to secure it laterally



5. Poor joint strength in production casing near surface



5. Poor joint strength in production casing near surface

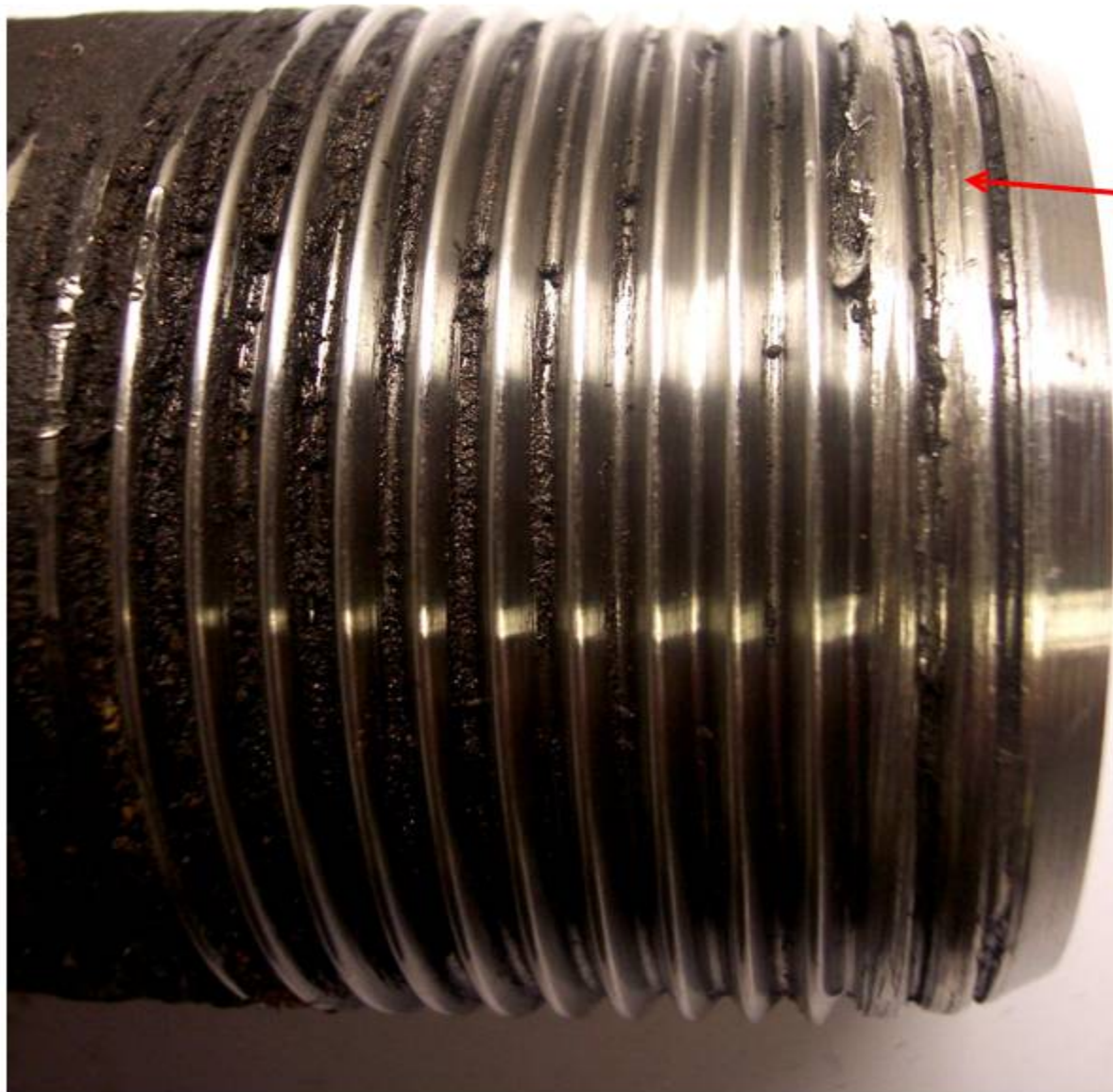


5. Poor joint strength in production casing near surface

- Situation

- Obviously, a production casing connection failed while frac treating the well
- High pressure and rebound of jumped casing causes surface casing connection to jump
- Mission control: “We now have liftoff.”

5. Poor jt strength in production casing near surface



Jumped thread
due to cross-
threading

5. Poor jt strength in production casing near surface

- Diagnosis – Two options
 1. Cross threaded connection – weak connection



5. Poor jt strength in production casing near surface

- Analysis – cross threading

1. Cross threading is common while running API connections
2. Best option to avoid cross threading: Stabber (to find sweet spot) and tong operator
3. Recent trend to top drive rigs & safety is taking stabber out of the derrick – increased risk of CT
4. Recent trend to make up csg with top drive – no tong operator – loss of CT awareness

5. Poor jt strength in production casing near surface

- Mitigation – Cross threading
 - Use experienced stabber/tong operator
 - If no stabber, level rig for exact alignment of elevators over hole
 - If no tong operator, switch to premium connections – cross-thread resistant thread form

5. Poor jt strength in production casing near surface

- Diagnosis – Two options
 1. Jump-out – hanging load exceeded joint strength
 2. Jump-out – hanging load exceeded joint strength



5. Poor jt strength in production casing near surface

- Analysis – Jump-out

- Jump-out pin has been deformed – pinched
- Threads unzipped – Why?

- API jt strength equation too optimistic - jumpout

$$P_j = 0.95 A_{jp} L \left[\frac{0.75 D^{-0.59} U_p}{0.5L + 0.14D} + \frac{Y_p}{L + 0.14D} \right]$$

- P_j = minimum joint strength
- A_{jp} = cross-sectional area under last perfect thread,

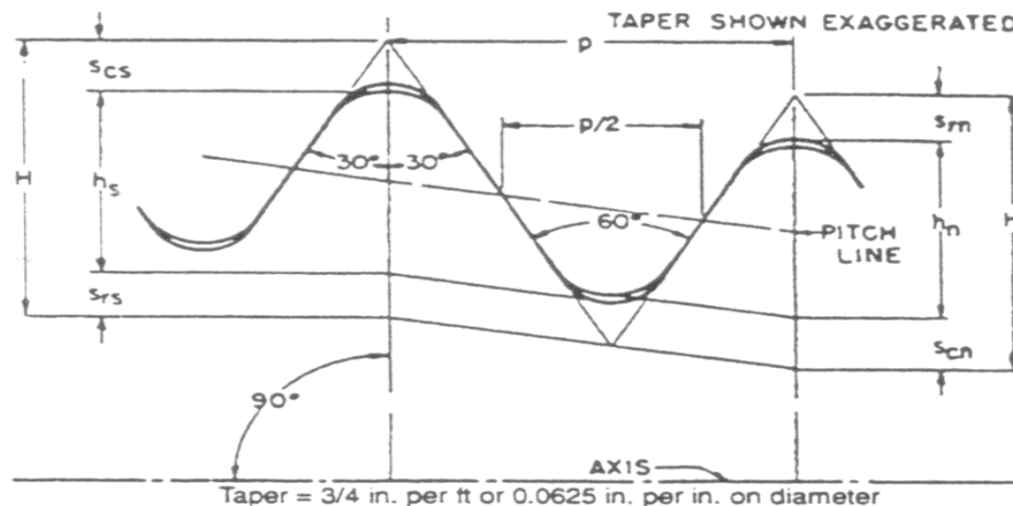
$$A_{jp} = 0.7854 \left((D - 0.1452)^2 - d^2 \right)$$

- L = engaged thread length = $L_4 - M$ for nominal make-up
- U_p = minimum ultimate strength
- D = outside diameter
- Y_p = minimum yield strength

5. Poor jt strength in production casing near surface

- Analysis – Jump-out

- Large OD pipe & nominal wall thickness (to avoid black crested threads) - thin wall under the pin thread
- Threading tolerances – more thin wall
- 30° load flank



5. Poor jt strength in production casing near surface

- Analysis – Jump-out
 - Cooling during pump job increases tension on casing hanger

$$F = -207 * \Delta T * A_p$$

5. Poor jt strength in production casing near surface

- Mitigation – Jump-Out
 - Make-up to no less than nominal position
 - Set minimum design factor = 2.00
 - In other words – cut joint strength in half
 - Do not allow tension to exceed half of book value - ever
 - Include temperature effect during pump job