REX2024
PRCI Research Exchange

Management of C-SCC

Yong-Yi Wang, Ph.D. and David Warman, CRES
Yohann Miglis, KMI

San Diego, California
February 28, 2024

LEADING PIPELINE RESEARCH

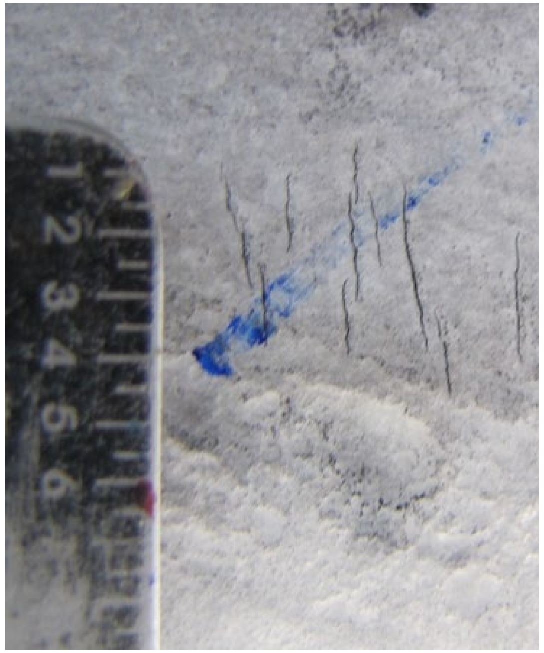
Pipeline Research Council International

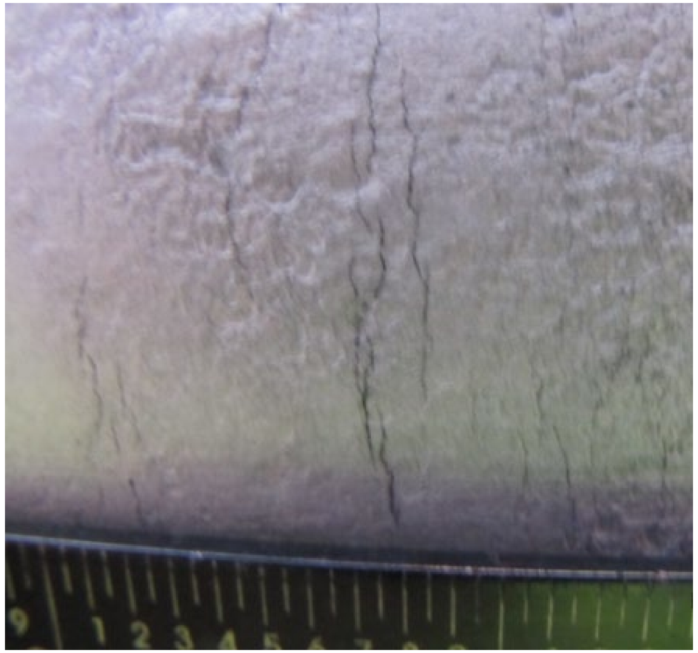
Overview

- **Examples of C-SCC**
- **Susceptibility**
- **Integrity Management**
  - Susceptibility and detection using data integration
  - Growth rate
  - FFS assessment
  - Repair and remediation
- **Next steps**

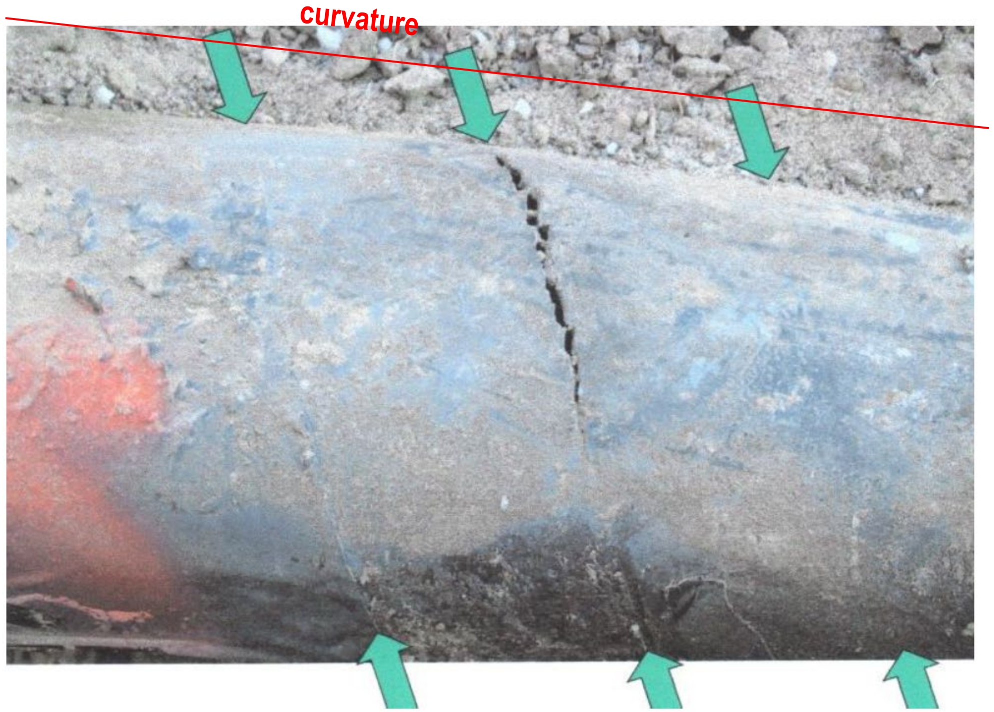
Examples of C-SCC

C-SCC, Non-Leak, Tape Coated



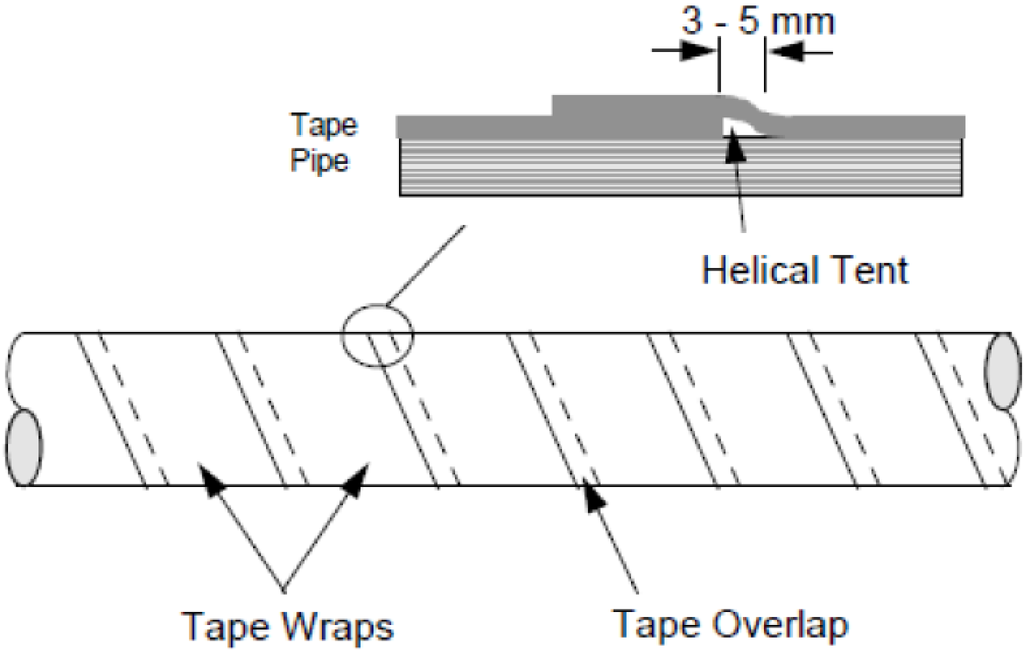


C-SCC related to Tape Overlap



Tape Overlap Areas

Over the ditch "Polyken" polyethylene tape wrap
Coating choice of the 1970's



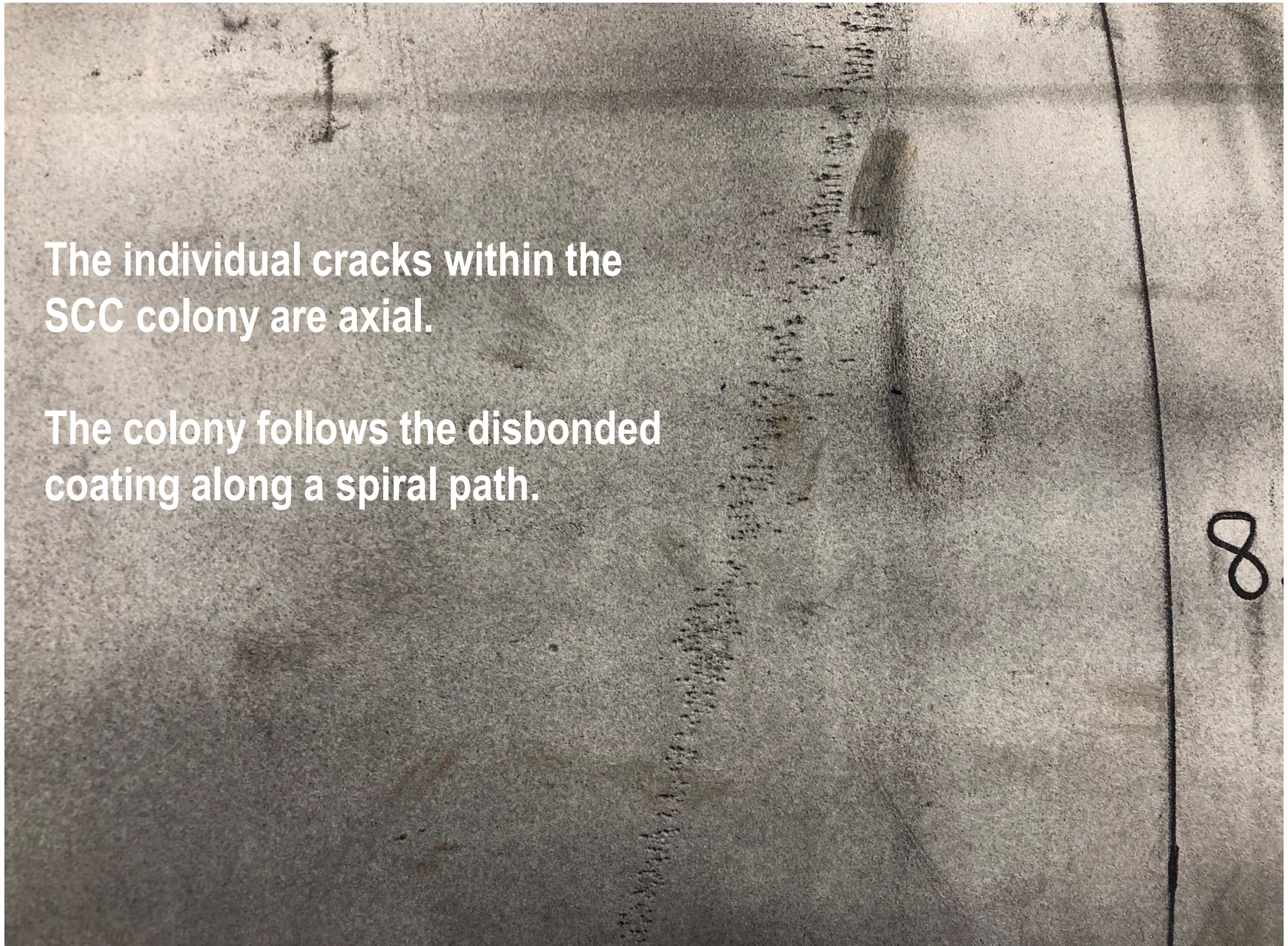
Complex SCC with Circumferential Component

- SCC in multiple directions

Complex SCC with Circumferential Component

- **Should this be treated as A-SCC or C-SCC?**

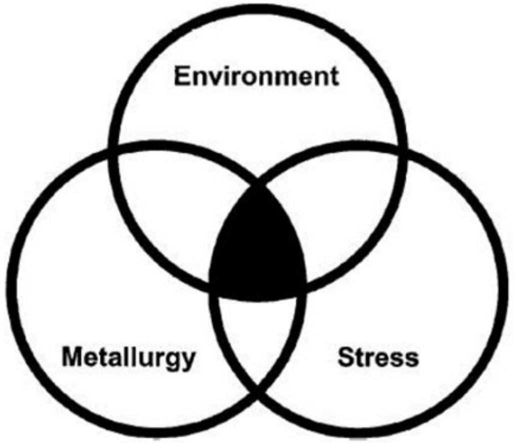
hoop



Susceptibility

Conditions for C-SCC

- **Condition 1 - Susceptible pipe material, surface condition and steel microstructure;**
  - Carbon steel is known to be a susceptible material.
- **Condition 2 - A potent cracking environment and tape coating**
  - Tape coating on pipe: when non-conductive plastic tape coatings become disbonded, the pipe surface is shielded from CP current
  - Over the ditch applied tape coatings can become disbonded due to potential application issues and/or soil stresses.
    - Including shrink sleeves (Note: some FBE coated pipelines in the 1980's utilized shrink sleeves at field joints)
  - Various soil types and ground moisture conditions conducive to NNpH SCC.
    - Anaerobic clay and silts are more susceptible.
    - NNpH SCC also found under Asphalt and Coal Tar coatings – but less frequent
- **Condition 3 - A tensile longitudinal/axial stress higher than the threshold stress**

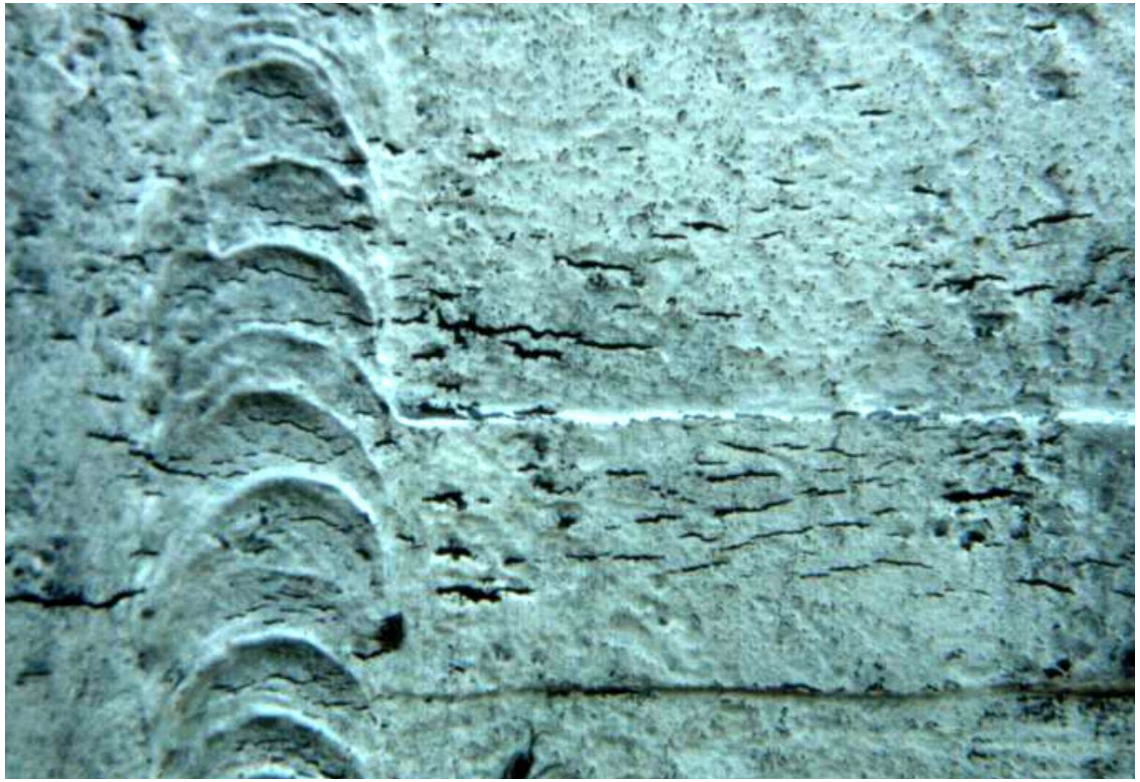


Coating Type	#	Percent
Tape	44	86%
Asphalt	4	8%
Coal Tar	2	4%
Shrink Sleeve	1	2%
Total:	51	

R. R. Fessler and A.D. Batte, "Criteria for Susceptibility to Circumferential SCC," Nov. 8, 2013.

A-SCC vs. C-SCC: Conditions 1 & 2

- **NNpH SCC does not seem to discrimination on the actual metallurgy of the carbon steel.**
- **Given the right environment conditions the NNpH SCC occurred without bias in:**
  - Base metal,
  - DSAW seam,
  - SMAW girth weld, and
  - HAZ of seam and girth weld
- **There is no evidence to suggest that the pipe that contains C-SCC has any unusual composition, microstructure, or mechanical properties.**



C-SCC: Condition 3

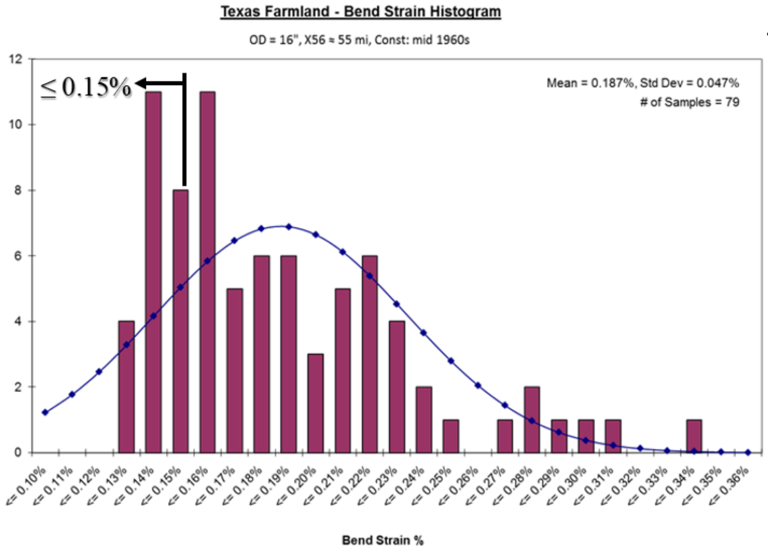
- **Tensile stress higher than a threshold stress**
  - For A-SCC, hoop stress greater than 50-60% SMYS leads to increased susceptibility, although A-SCC has been found at lower hoop stress level.
- **Axial/longitudinal stress for C-SCC**
  - Axial/longitudinal stress from Poisson's effect alone is below the threshold stress.
  - Stresses from non-operational conditions must exist.
- **Sources of axial/longitudinal stresses**
  - Residual stresses from pipe/fitting manufacturing and field bending
  - Construction stresses
  - Stresses from post-construction settlements
  - Geohazards

Longitudinal/Axial Strain

56-79 strain features have long. stress > 90% SMYS

1.0-1.4 features / per mile

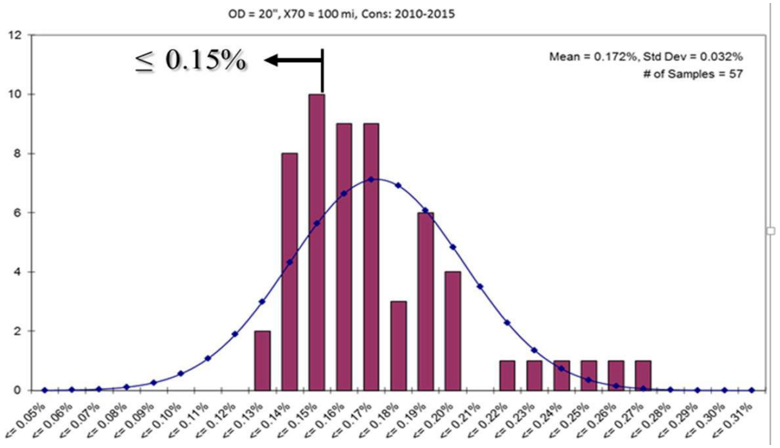
Highest tension strain = 0.42%

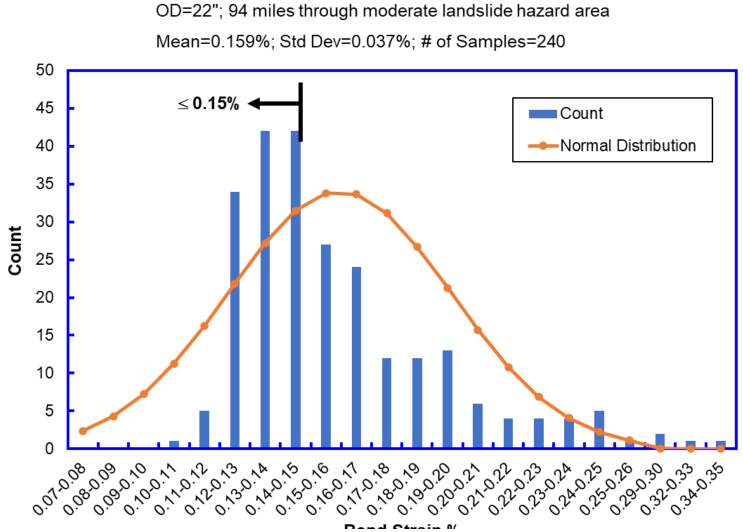


37-57 strain features have long. stress > 90% SYMS

0.4-0.6 features / per mile

Highest tension strain = 0.35%

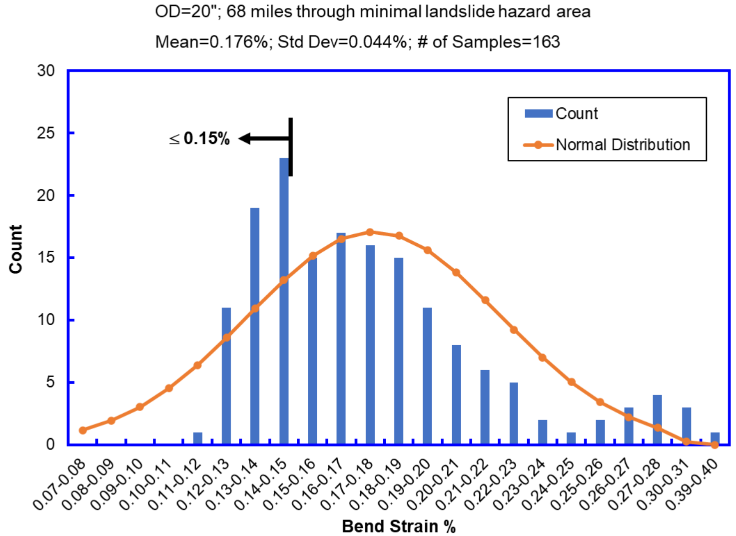




125-234 strain features have long. stress > 90% SYMS

1.3-2.5 features / per mile

Highest tension strain = 0.43%



109-162 strain features have long. stress > 90% SYMS

1.6-2.4 features / per mile

Highest tension strain = 0.48%

Ref: Wang, Y.-Y, Liu, B., and Fleck P., "Strain-Based Design and Assessment of New and Ageing Pipelines," Technology for Future and Ageing Pipelines, 2022, Gent, Belgium.

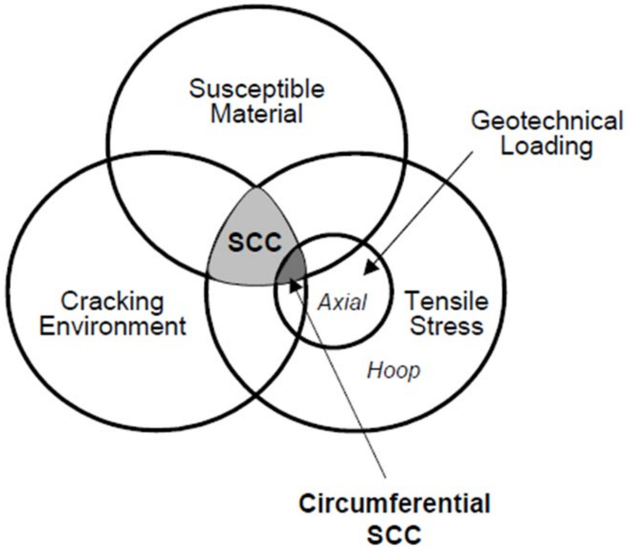
Bend Strains > 0.15% in combination with other functional loads is equal to longitudinal stress > 90% SMYS.

Longitudinal/Axial Strain - Implications

- **The strain features shown were not related to identifiable geohazards.**
- **Most of the strain features were related to tie-ins, minor settlements, and roping**
- **Approximately 0.5-2.5 sites per mile of pipeline has longitudinal stress greater than typical design stress limit of 90% SMYS.**
  - Sites exceeding 50-60% SMYS would be at a greater frequency.
- **The high-end of total tensile strain is in the range of 0.35-0.50%.**

C-SCC – Emerging Trends

- **C-SCC can exist in locations not associated with identifiable geohazards.**
  - Many operators are seeing most of the C-SCC locations are not in areas of geohazards.
  - Some operators have observed a strong correlation with geohazards
- **Isolated incidents attributable to C-SCC are mostly leaks, not ruptures.**



From API RP 1176 2016 Edition

~~"Geotechnical Loading" is no longer an accurate description.~~

Part 3 Integrity Management Process

- Susceptibility and detection of C-SCC
- Growth rate
- FFS
- Repair and mitigation

Integrity Management

Susceptibility and Detection of C-SCC by Data Integration

Susceptibility and Detection Using Data Integration

- **Areas where A-SCC has been found since the environmental conditions exist**
- **High axial/longitudinal stresses**
  - ILI-IMU, bend strain features
  - Geohazards
  - Bends, challenging construction conditions
  - Tie-in locations
  - Crossings
- **Other ILI indications (e.g., MFL)**
  - Areas of very low level metal loss indicative of disbonded coating
  - Signals present in the axial MFL, but not the circumferential MFL
  - Axial length to circumferential width of signals only present in the axial MFL
  - Circumferential patterns in the ID/OD discrimination signals indicative of a deeper crack

Integrity Management

Growth Rate

Growth Rate & Dormancy

- **Possible sources of axial/longitudinal stresses**
  - Residual stresses from pipe/fitting manufacturing and field bends
  - Construction stresses
  - Stresses from post-construction settlements
  - Geohazards
- **These stresses have different characteristics.**
  - Residual stress does not increase over time. The magnitude may decrease after cracking if external loading does not change.
  - Construction stresses most likely do not increase with time.
  - Stresses from post-construction settlements most likely increase in first a few years, then stabilize.
  - Stress from geohazards could increase over time.
  - Most axial/longitudinal stresses are not cyclic at high frequency, different from hoop stress in liquid pipelines.

Depth Growth Rate: A-SCC vs. C-SCC

- **Time average methodology for A-SCC**
  - A 5-10 yr initiation period: coating breakdown and development of an environment for crack initiation.
  - Hoop stress is above the threshold stress level for SCC initiation and growth.
- **C-SCC**
  - The 5-10 yr initiation period still applies.
  - Magnitude of axial/longitudinal stresses over time varies, depending on the nature of the stresses.
  - Two scenarios
    - Scenario 1: If the axial stress is from residual stresses, locked-in installation stress and or minor settlement shortly after construction, the time average method applies.
    - Scenario 2: If the axial/longitudinal stress is from land movement with increasing stress over time, then multiple ILI may be required to account for possible varying growth rates.

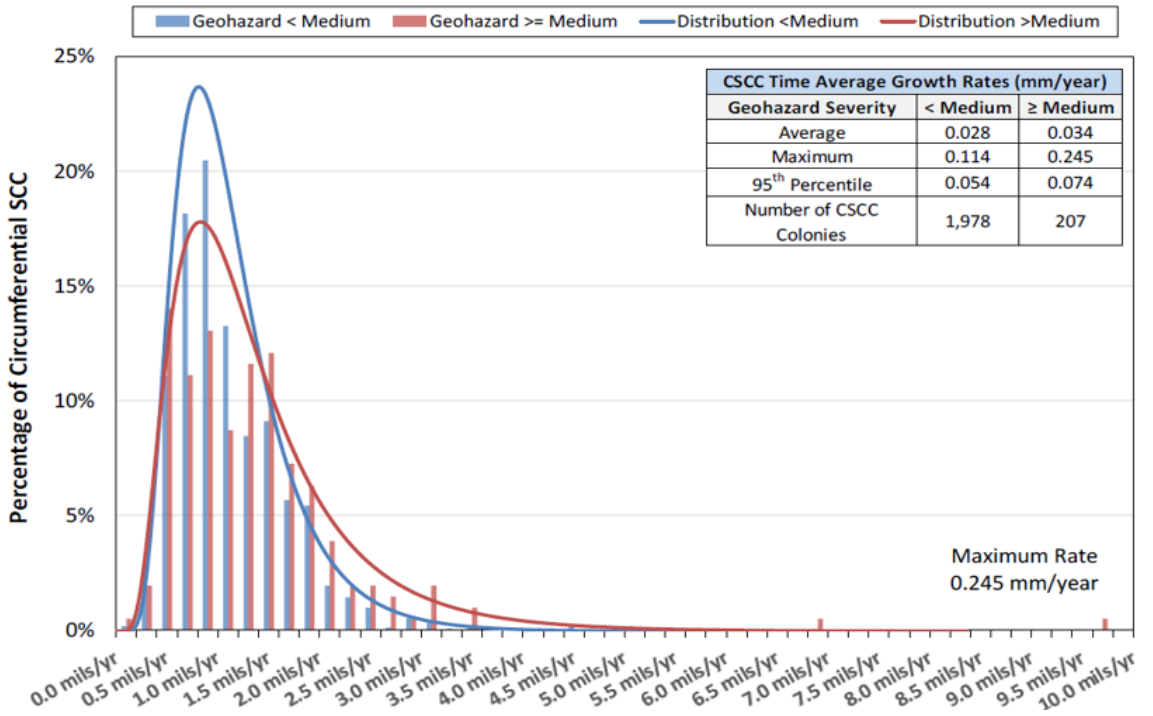
Growth Rate & Dormancy

- **It's conceivable**
  - Some forms of stresses contributing to C-SCC initiation might not be high enough to
    - Cause continued growth
    - Lead to leak or rupture
  - Other forms of stresses can increase in magnitude
    - Maintain growth rate
    - Cause leak or rupture
- **Observations from incidents**
  - Isolated incidents attributable to C-SCC are mostly leaks, not ruptures.
- **Takeaway**
  - It is useful to look at growth rates for different stress scenarios.

C-SCC – Time Averaged Depth Growth Rate

- **One operator**
  - NNpH SCC for diameters ≤ 12.75” have similar axial and circumferential growth rates.
  - The table below is based on SCC that have failed and is representative of the more aggressive growth rates

Sample	Mean	Std Dev	95% of Distribution
	mils/yr	mils/yr	mils/yr
All ≤ 12.75 in.	4.28	1.31	6.44
C-SCC	4.72	1.46	7.13



N. Bates, M. Brimacombe, and S. Polasik, “Development and Experiences of a Circumferential Stress Corrosion Crack Management Program,” IPC2018-78315, Calgary, Alberta, Canada, September 24-18, 2018.

- **Another operator**
  - A larger population
  - 95 Percentile growth rates for NNpH C-SCC as: 2.1-2.9 mils/yr and a maximum of 9.6 mils/yr

Part 3c

Integrity Management

FFS Assessment

Strain-Based Assessment

- **Stress or strain likely to have integrity consequences are that at high magnitude**
  - Stress > 90% SMYS
  - Strain > 0.2%
- **The state of loading can be more precisely measured in strains than stresses at this stress/strain level.**
- **Stress-based assessment procedures tend to**
  - Become less accurate when resolving strains
  - Produce overly conservative outcomes, leading to unnecessary mitigations

Benefits of Strain-Based Assessment – Effective Mitigation

- **Mitigation of circumferential (C-SCC) features, example**
  - 3000+ identified features
  - Using SBA, about 2% of the features did not pass the first screening.
    - Further analysis would reduce this number even further
      - E.g., the 2% features include high bend strain locations from manufactured or field bends
  - Using stress-based FFS, many more features (>>2%) failed the screening.

Benefits of Strain-Based Assessment - Safety

- **SBA puts focus on managing axial/longitudinal stress/strain.**
- **Safety margin = strain capacity – strain demand**
- **When working with geohazards, internal pressure is not the primary driver.**
- **Safety must be managed by checking the safety margin in axial/longitudinal strains.**
  - Pressure reduction may not get the safety margin as one might expect.

Example Applications

- **C-SCC was identified through ILI.**
- **The sites were also identified as potentially having geohazards.**
- **The sites are operating at lower pressures than the pressure at time of the ILI.**
- **Desired:**
  - Access the sites at a later time when the ground conditions are more favorable.
  - Maintain service
- **SBA was done to**
  - Determines the time window for mitigation
    - Determine the margin of safety due to low operating pressure, e.g., increase tensile strain capacity (TSC)
    - Count for SCC growth over time, lead to reduction to TSC
  - Safety margin at different sites, thus priority of mitigation
- **Follow-on**
  - Confirmation of C-SCC
  - Mechanical tests to facilitate the determination of TSC

Part 3d

Integrity Management

Repair and Remediation

Repair and Mitigation

- **Pipe replacement and type B sleeves are typical repair methods**
- **Many of current repair approaches for axial flaws have not been designed and validated for high longitudinal stress conditions.**
- **Need to consider loads during and after repair**
- **Specific issues**
  - Grinding: minor buffing up to certain percentage of wt should be OK, provided the hoop dimensions are properly limited.
  - Composite wraps: not designed for pure axial loads, can reduce stress from bend loads
  - Type-A sleeves: can reduce stress from bend loads
  - Compression sleeves
    - Reduce stress from bend loads
    - Some protection against axial load due to shrink fit plus shear bond.
    - Increase TSC of carrier pipe due to hoop stress reduction

Part 4 Next Steps

Annex N of API RP 1176, Management of Circum. Cracks

- Background and Scope
- Comparing and Contrasting Axial and Circumferential Crack Threats
- Susceptibility
- Detection, Characterization, and Sizing of CC
- Growth Rate
- Overall Management
- Overview of Fitness-for-Service Assessment Methods
- Mitigation
- References

New Initiative Being Considered

- **Joint effort**
  - Pipeline operators
  - ILI vendors and SMEs
  - FFS SMEs
- **Key issues to be resolved**
  - Susceptibility from latest findings
  - Growth rate / dormancy
  - Integrity assessment

Concluding Remarks

- **C-SCC has been identified by multiple operators.**
- **C-SCC does not appear to be a major integrity threat.**
- **There is no established practice for managing C-SCC.**
- **What would be a balanced practical approach?**
  - Recognize the differences between A-SCC and C-SCC
  - The stresses that drive C-SCC are different from those that drive A-SCC
- **New concepts**
  - Safety margin primarily based on axial/longitudinal strains
  - Strain-based assessment
- **Gaps**
  - ILI
  - Susceptibility
  - Growth rate & dormancy

thank you

REX2024

PRCI Research Exchange

Yong-Yi Wang

CRES

614-419-2366

ywang@cres-americas.com