Considerations for Offshore Pipelines / Pipelines That Cross Navigable Waterways and Water Bodies

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Workshop - Roadmap for CO2 Transport Fundamental Research

February 22, 2023

Overview

- Some known issues for CO_2 pipelines
  - Thermodynamics (Joule-Thomson cooling, hydrate formation, etc.)
  - Corrosion
  - Fracture propagation control
  - Use of elastomers
  - Safety / dispersion / impact radius
  - Re-purpose / new construction
- Broad issues related to CO_2 pipelines crossing or near water bodies
- Examples of pipelines failures that exposed systemic gaps in current standards and practice
- Takeaways from those incidents and recommended research and enhancements

Overview of Potential Issues

- Scope
  - CO_2 pipelines crossing OR near navigable waterways and water bodies
- What happens if there is leak in a body of water?
  - Jet stream injected into the surrounding water, resulting in a bubble plume
  - Hazards similar to a natural gas pipeline
    - Destabilizing buoyance, affecting surface vessels
  - Hazards unique to CO_2 pipelines
    - Dispersion of CO_2 and related health risks
- Mechanical damage
  - Dropped anchor, or being hooked by dragging anchor
  - Trawl gear impact
  - Sinking vessel
- Existing practice on preventing mechanical damage of pipelines can be applied.

Delhi CO2 Pipeline Failure at Satartia, MS, 02/22/2020

- On February 22, 2020, a CO2 pipeline operated by Denbury ruptured in proximity to the community of Satartia, Mississippi.
- The rupture followed heavy rains that resulted in a landslide, creating excessive axial strain on a pipeline weld.
- Pipeline was installed in 2009.

- Delhi Pipeline
  - Installed in 2009
  - 24" OD X80 ERW pipes
  - 77 miles
  - CO2 is used for enhanced oil recovery (EOR)

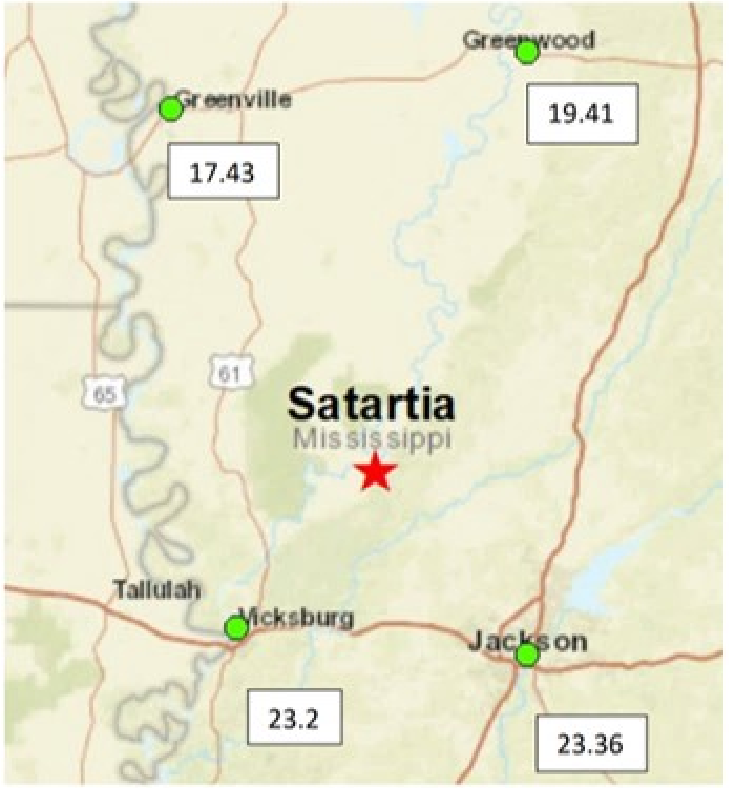

Figure 2: Vehicle is Parked on HWY 433 - The White is Ice Generated by the Release of CO_2 - The Blue Arrow Points North (Aerial Drone Photograph Courtesy of the Mississippi Emergency Management Agency)

Wesley Mathews, "Failure investigation report – Denbury Gulf Coast Pipelines, LLC – Pipeline Rupture / Natural Force Damage," US DOT PHMSA OPS, May 26, 2022.

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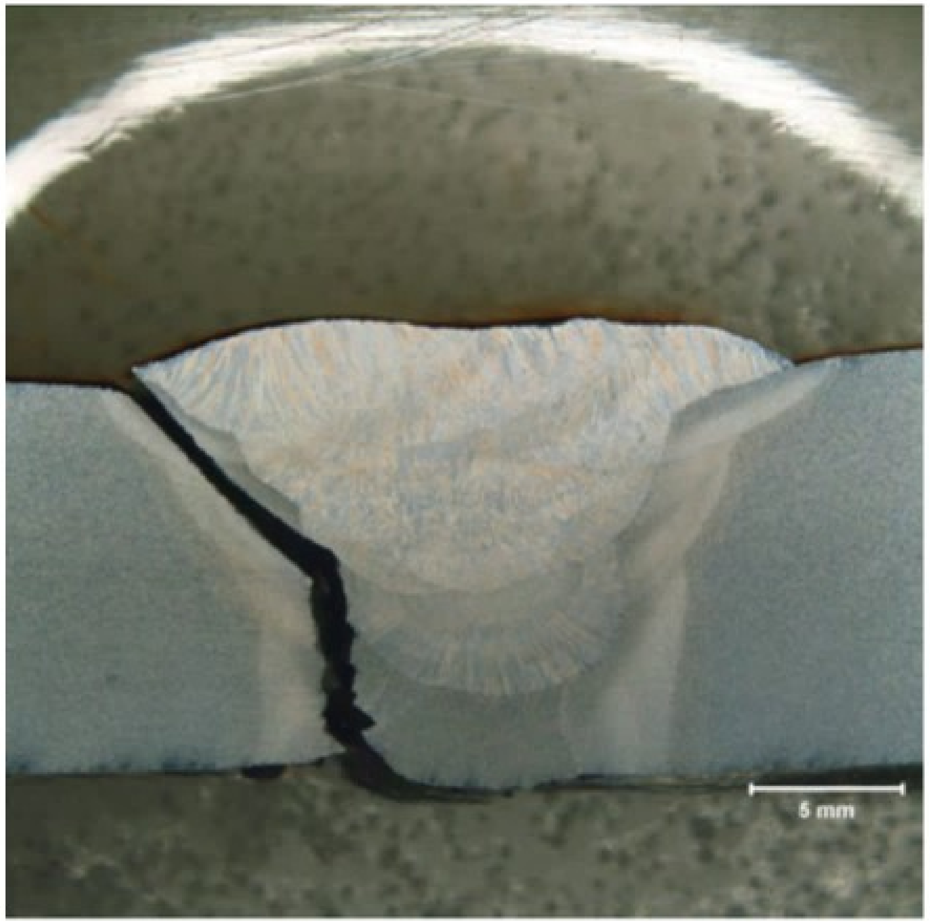

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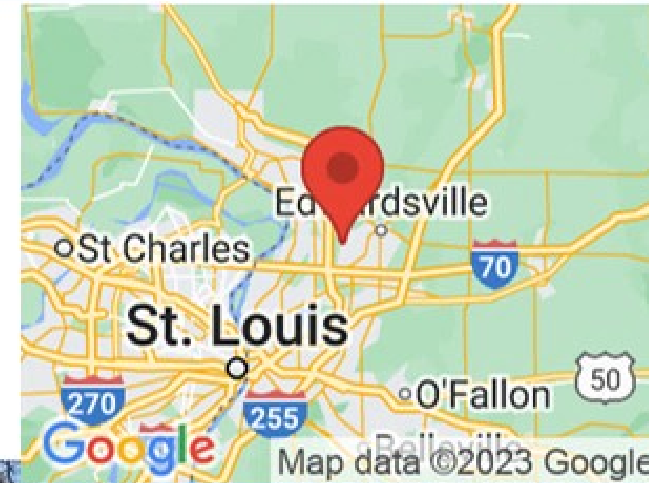
An Earlier GW Failure of Delhi CO_2 Pipeline, 11/9/2018

- On November 9, 2018, the Delhi Pipeline experienced a girth weld rupture at a valve location during pipeline reloading activities, and not attributed to natural force damage.
- The release was the result of large thermal differential stresses being exerted on the pipeline from CO_2 loading at two different locations at the same time.
- The pipe between the two loading points shrank due to chilling from the CO_2, causing the girth weld connecting the pipeline to the valve body to rupture.
- The report found no evidence of inadequate mechanical properties or chemical composition anomalies in the ruptured weld.
- Denbury updated their procedure to prevent similar occurrences.

Wesley Mathews, "Failure investigation report – Denbury Gulf Coast Pipelines, LLC – Pipeline Rupture / Natural Force Damage," US DOT PHMSA OPS, May 26, 2022.

Woodpat Pipeline Release, 03/11/2022

- On March 11, 2022, at about 8:15 a.m. local time, Woodpat pipeline, a 22-inch-diameter hazardous liquids pipeline operated by Marathon ruptured in Edwardsville, Illinois.
- The rupture resulted in the release of about 3,900 barrels of crude oil, some of which entered Cahokia Creek, a tributary of the Mississippi River.
- Woodpat pipeline
  - Constructed in 1949
  - 22" OD
  - Purchased by Marathon in 1968.
- A complete circumferential separation at a girth weld at the rupture origin

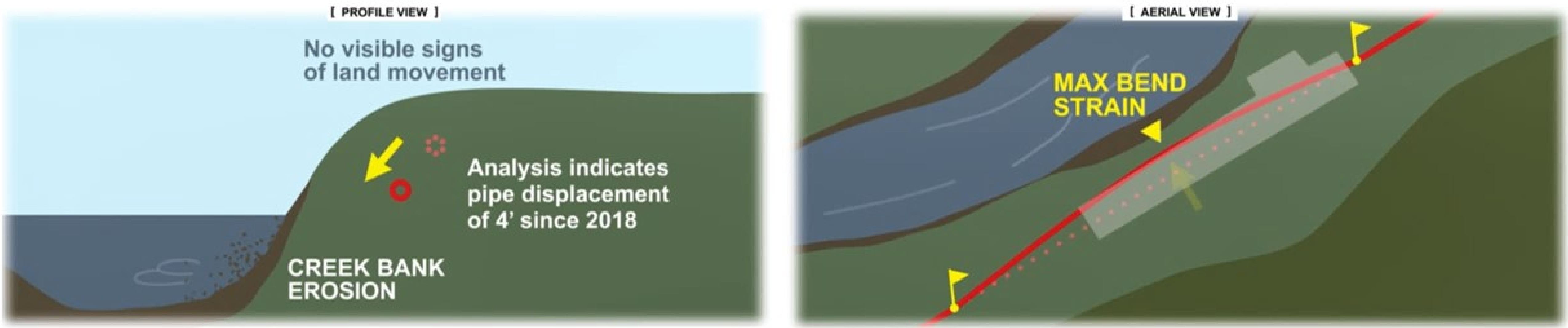


NTSB Docket PLD22FR002, March 11, 2022, Accident No. PLD22FR002.

Woodpat Pipeline Release, 03/11/2022

- Previous in-line inspections and field studies had identified movement of the pipeline, erosion, and soil subsidence in the area near the rupture site.

NTSB Docket PLD22FR002, March 11, 2022, Accident No. PLD22FR002.



- Tensile strains were generated from bending of the pipe due to down-slope movement of the soil on the riverbank.

Information session hosted by NTSB, PHMSA, and Marathon on April 5, 2022.

Keystone Pipeline Release, 12/7/2022

- December 7, 2022 , Washington County, Kansas.
- Spill into Mill Creek
- Pipeline entered into service 2011.

https://www.smithsonianmag.com/smart-news/keystone-pipeline-leaks-14000-barrels-of-oil-in-kansas-180981275/

https://www.npr.org/2022/12/17/1142675809/cleanup-for-keystone-pipeline-oil-spill-kansas

Keystone Pipeline Release, 12/7/2022

- "Failure occurred due to a combination of factors, including bending stress on the pipe and a weld flaw at a pipe to fitting girth weld that was completed at a fabrication facility."
- "Although welding inspection and testing were conducted within applicable codes and standards, the weld flaw led to a crack that propagated over time as a result of bending stress fatigue, eventually leading to an instantaneous rupture."
- "The cause of the bending stress remains under investigation as part of the broader third-party root cause failure analysis."

TC Energy, https://www.tcenergy.com/incident/milepost-14-incident/#:~:text=On%20December%207%2C%202022%2C%20TC,operational%20to%20all%20delivery%20points.

Common Features of the Incidents

- Failures occurred at girth welds.
- Vintage of pipelines
  - Woodpat: old (1949)
  - Other three failures: new (~10 years)
- Three failures of new pipelines
  - Pipes made to spec
  - Welding and inspection to spec
  - Stresses or natural forces were attributed as the cause of failures.

Girth Weld Failures in Newly Constructed Pipelines

- Recent systematic investigation started ~2015
- Incidents
  - occurred in-service and during hydrostatic testing
  - 30+ incidents.
    - ► US
    - ► Asia
    - ► South America
  - Grade: X52 to X80
  - Manual or semi-automatic welds
- Some incidents before 2015 may have similar contributing factors.

Incident No.	OD (inch)	Grade	Nature of Incident	Approximate Elapsed Time for Start of Service
1	20"	X70 PSL2	In-Service Rupture	1 Year
2	30"+	X80/X70	In-Service Rupture	6 years
3	12.75"	X52	In-Service Leak	14 years
4	30"	X70M	Hydrostatic Leak	N/A
5	30"	X70	Hydrostatic Leak	N/A
6	42"	X70 PSL2	In-Service Rupture	3 years
7	12.75"	X52/X65	In-Service Rupture	4-5 years
8	24"	X70	In-Service Rupture	3.5 years
9	36"	X70	Hydrostatic Leak	N/A
10	Information can't be released	X70	In-Service Rupture	Less than 1 year

Wang, Y.-Y. and Jia, D., "Review of Girth Weld Incidents in Newly Constructed Pipelines and Identification of Contributing Factors," PRCI MATH-5-3B, report catalog number PR-350-174507-R04, August 2022.

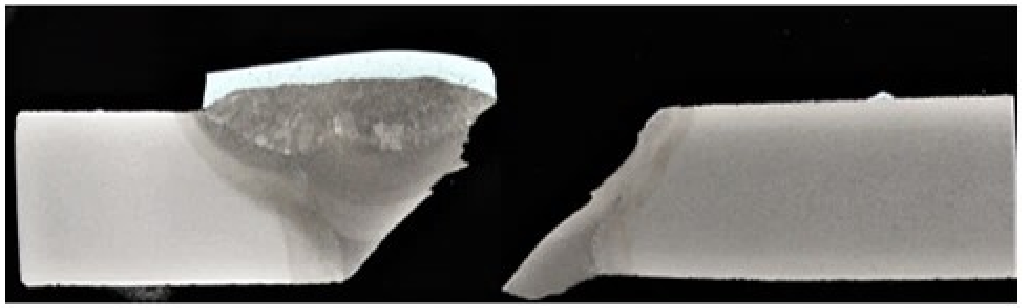
PHMSA Advisory – Damage by Earth Movement

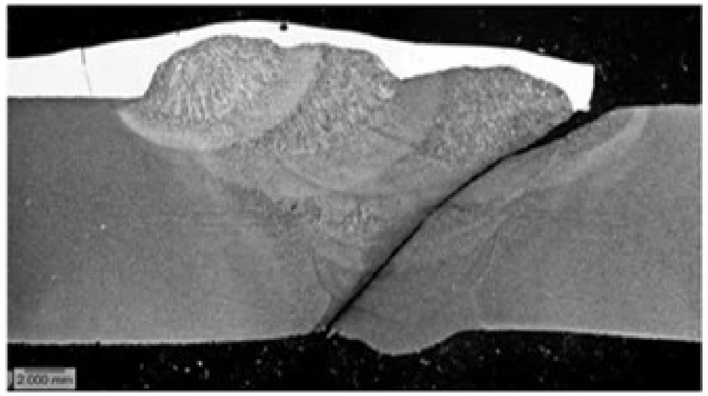
- Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by Earth Movement and Other Geological Hazards, June 2, 2022.
  - Lists many failures caused by earth movement.

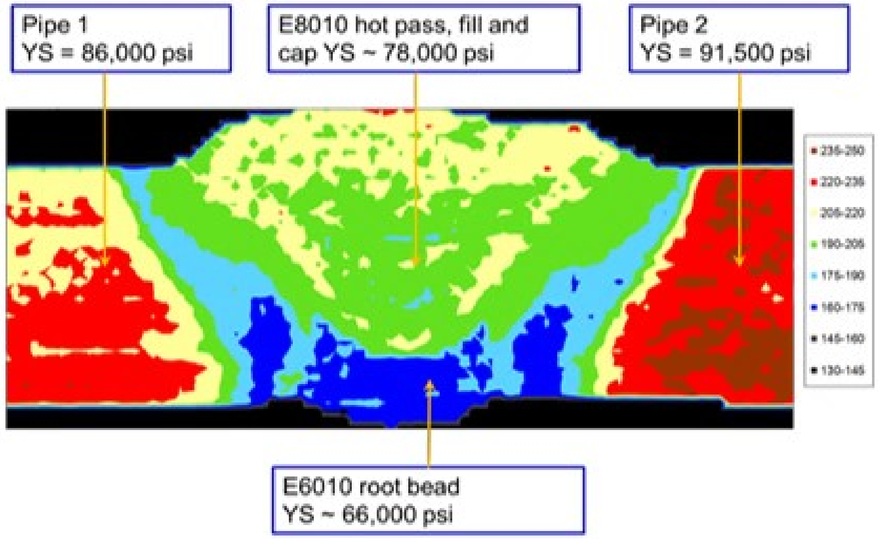
https://www.phmsa.dot.gov/regulatory-compliance/phmsa-guidance/pipeline-safety-potential-damage-pipeline-facilities-caused-by-earth-movement-and-other-geological-hazards

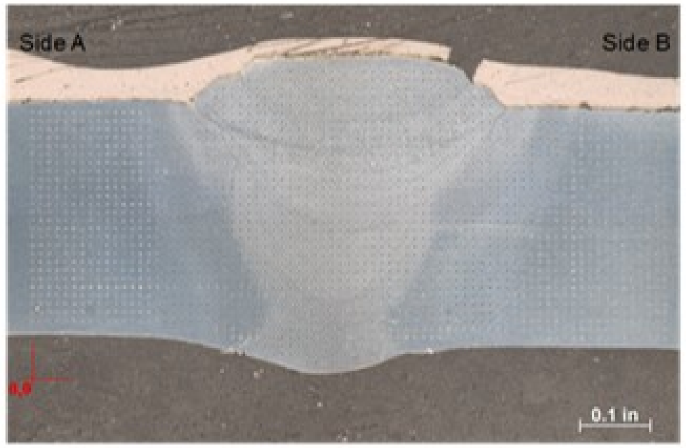
Major Contributing Factors to Observed Failures

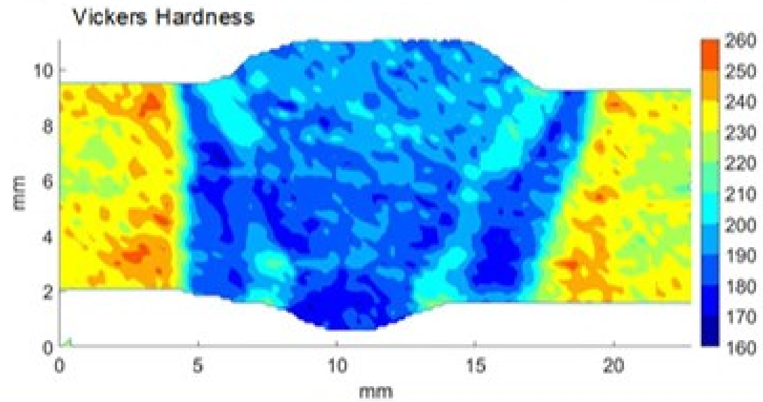
- ❑ Weld strength undermatching
- ❑ HAZ softening
- ❑ Elevated stress











Pipelines are NOT Long Pressure Vessels

- Pressure vessels: level of longitudinal stress is lower than that of hoop stress.

Pipelines are NOT Long Pressure Vessels

- Longitudinal stresses in pipelines can exceed yield strength, higher than hoop stress.

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Wang, Y.-Y., et al., "Management of Ground Movement Hazards for Pipelines," JIP report, February 28, 2017, https://ingaa.org/management-of-ground-movement-hazards-for-pipelines/

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Systemic Gaps - Capacity

- <u>Capacity, i.e., ability to resist load, stress, or strain without failure</u>
- Weld integrity has been viewed primarily through the prism of weld flaws and toughness.
  - While these factors continue to be important, welds can fail prematurely in the absence of these factors.
- Weld strength undermatching and HAZ softening can lead to low tolerance to longitudinal strains.
  - Weld strength undermatching is permitted by most standards.
  - The level of HAZ softening has gotten worse in recent decades due to changes in steel making and moving to higher strength linepipes.

Systemic Gaps – Demand

- <u>Demand, i.e., load, stress, or strain applied to pipelines</u>
- In contrast to hoop stress, longitudinal stress is not controlled by operational parameter like internal pressure.
- In most cases, the level of longitudinal stress is unknown and can have a very large range.
- High longitudinal stresses come from
  - Construction
  - Post-construction settlements
  - Geohazards
- Design requirements for such stresses, or execution of the requirements, are weak or non-existent.
- It's not uncommon for pipelines to operate beyond its code-required design limits.

Systemic Gaps

- Designs do not consider actual construction and field conditions.
  - Longitudinal stresses from construction and actual field conditions are greater than code design limit.
- Girth weld procedure qualification requirements are insufficient to meet the stresses observed in the fields.
- The permitted pipe strength ranges for a given grade are not taken into account in girth welding procedure qualification requirements.

Takeaways

- Longitudinal stresses on a pipeline
  - Varies greatly by location
  - Can be very high at some locations
  - Not controlled by operational means
- Failure of girth welds can be prevented even in the presence of high stresses, including those imposed by geohazards.

Key Takeaways and Next Steps

- Unique areas for CO_2 pipelines in water bodies
  - Dispersion modelling
  - Potential impact on health and safety
    - Cargo vessels
    - Ships with high population density
  - Response plan

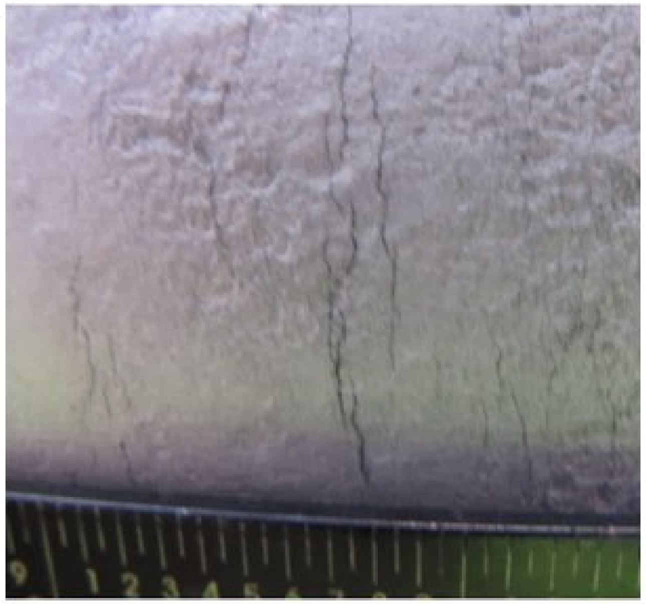
Key Takeaways and Next Steps – New Pipelines

- For dense phase transportation, high strength linepipes would be used.
  - Potential need for crack arrestors
  - Current minimum requirements in standards is not sufficient for girth weld integrity.
  - <u>Girth weld failures in newly constructed pipelines is an emerging risk that is poorly recognized[1].</u>
- Next steps
  - Systematic look - develop amended requirements in
    - Design
    - Material specifications
    - Welding and inspection
    - Integrity management, including geohazards
  - Technology
    - Full-scale tests and validation of models of robust girth welds of new pipeline steels
    - Requirements for crack arrest, including the use of crack arrestors

[1] Wang, Y.-Y and Jia, D., "Managing Standards with Evolving Industry Practice – Lessons Learned from Girth Weld Failures in Newly Constructed Pipelines," Technology for Future and Ageing Pipelines, 2022, Gent, Belgium.

Key Takeaways and Next Steps – Repurposed Pipelines

- Most existing energy pipelines would not be suitable for dense phase transportation due to pressure requirements.
- Next steps
  - Systemic look – identify areas of potential deficiencies
- Technology
  - Management of seam and girth weld flaws
  - Check if there is increased potential of
    - C-SCC (circumferential stress corrosion cracking)
    - Corrosion with significant circumferential extent
  - Interacting threats
    - Cracking
    - Weak welds (strength, toughness, cracking)
    - Geohazards



Key Takeaways and Next Steps

Take research outcomes to codes and standards!

Remove barriers and enhance communications about standards governing different domains of a pipeline's life.

Q&A

- Thank you!