API RP 1187 and Integrity-Centric Geohazards Management

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Agenda

- Part 1 2:00 - 2:30
  - Part 1.1 Introduction of the presenter
  - Part 1.2 Achieving goal through actions
  - Part 1.3 Terms and concepts
- Part 2 2:30 - 4:00
  - Part 2.1 Introduction of API 1187
  - Part 2.2 Geohazard management
  - Part 2.3 Integrity-centric approach, concept
    - Why
    - Strain demand
    - Tensile strain capacity
    - Compressive strain capacity
    - SBA FFS
  - Questions
- 4:00 - 4:15 Break

Agenda

- Part 3 4:15 - 5:30
  - Part 3.1 Integrity-centric geohazards management program
  - Part 3.2 Data collection and continuous improvement
  - Questions
- Part 4 5:30 - 6:00
  - Part 4.1 Practical examples
  - Part 4.2 Building effective geohazards management program – high-level strategy
  - Closure

Acknowledgement

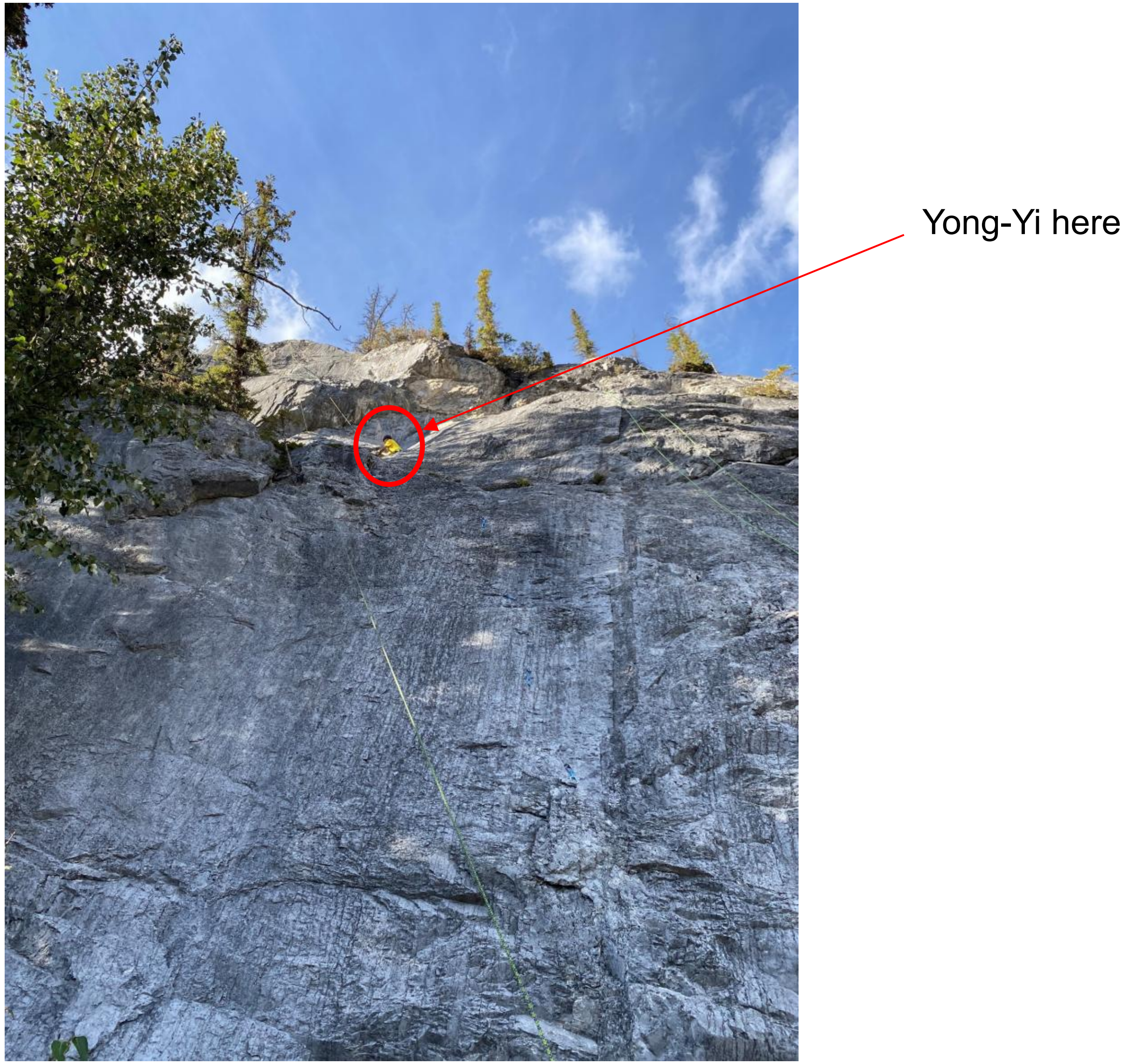
- Staff at CRES
- Pipeline operators
- PRCI
- INGAA
- PHMSA
- CER
- Partners in INGAA projects and API RP 1187 (some slides were modified from joint presentations)
  - Alexander McKenzie-Johnson
  - Bailey Theriault

Part 1.1

About the Presenter

Presenter – Dr. Yong-Yi Wang, Person

- Grew up in a small town in northern China.
- Undergraduate education in Shanghai, China
- Graduate education in the US
- S.M. and Ph.D. at MIT
  - Major: Mechanics and Materials
  - Minor: Business administration
- Hobbies
  - Swimming
  - Rock climbing
  - Gardening



Presenter – Dr. Yong-Yi Wang, Professional Life

- 30+ years of experience in consulting/research for the pipeline industry
  - Work with almost all stakeholders: regulators, standards committees, operators, service providers
- Founded CRES in 2007
- Industry leadership
  - Chair, Fracture Mechanics subcommittee of API 1104
  - Chair, Geohazards Management and Strain-Based Design and Assessment Track, IPC
  - Chair, Work Group on the Management of Circumferential Cracks, API RP 1176
  - A lead author for several PRCI, JIP, INGAA, and API documents on the management of geohazards
- Authored over 180 technical papers on pipeline integrity assessment, geohazards management, materials, welding, and fracture mechanics.
- Most known for strain-based design and assessment
- Awards
  - Honoree of distinguished lecture series, IPC 2018
  - Distinguished researcher, PRCI

Presenter – Dr. Yong-Yi Wang, Character

- Grateful
- Positive
- Hardworking
- Critical thinking
  - Don’t take authority at its face value
- Open-minded
  - “Everyone knows something you don’t.”
- Love to connect different subject areas
- Ask lots of questions

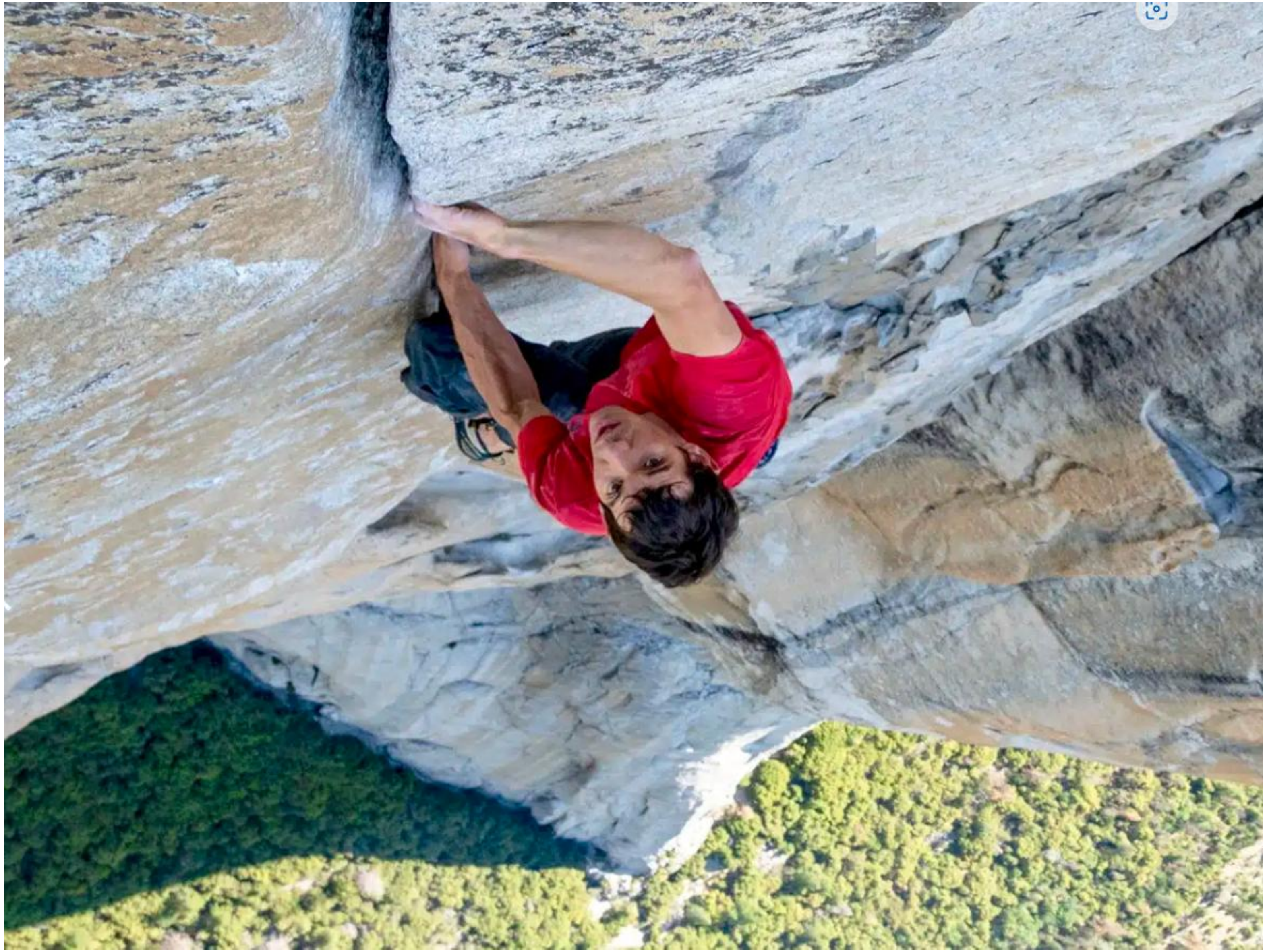
Part 1.2

Achieving Goal through Actions

Action Can Be Hard

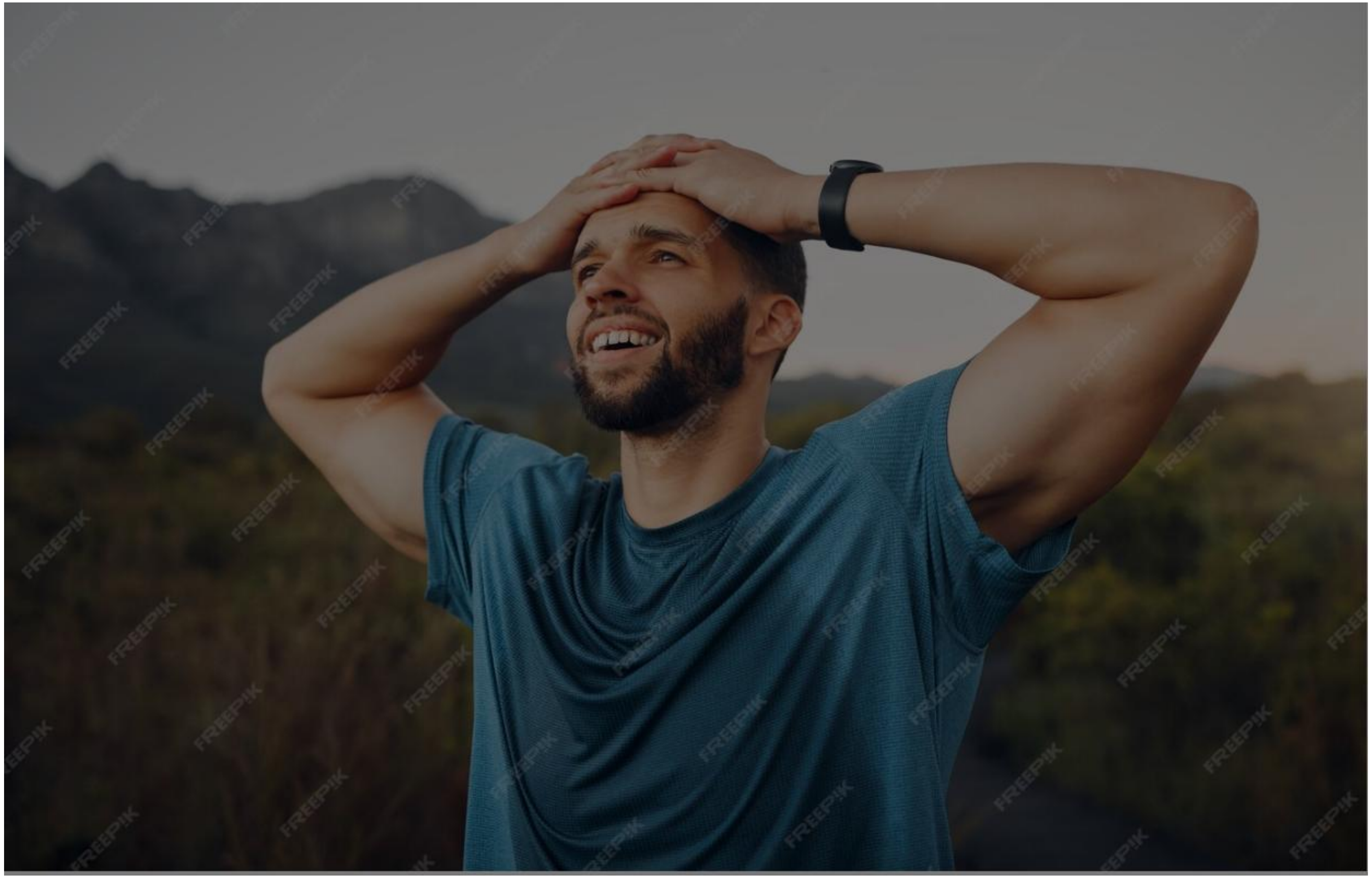
Action Can Be Dangerous, Free Solo

Action Can Be Dangerous, Free Solo



Reward Can Be Exhilarating

- “The best part of exercise is when it’s over.”



Our Goal for Geohazards Management

- Build a geohazards management program to achieve near-zero incident rate
- Geohazards may be an act of god.
- Leak or rupture is not an act of god.

How Do We Get There?

- Kicking down walls
  - Design/construction
  - Geohazards
  - Integrity
  - Mitigation
- Data integration, use all available tools, interdisciplinary approach
  - Construction records
  - Mitigation experience
  - Failure analysis
  - ILI
    - Monitoring
    - Assessment
- Holistic - life cycle

How Do We Get There?

- The most effective solutions can be had when we think and act across borders.
- Example: geohazards management
  - Traditional hazards-focused approach + strain-based assessment
  - Build systems
    - API RP 1187
    - API RP 1176
    - ASME B31.8S
    - IPC Track 6 Geohazards Management & SBA
- Example: low strain failure of girth welds
  - ASME B31.4 & B31.4
  - API 5L
  - API 1104
  - Construction practice

Getting There – This Tutorial

- Understanding API RP 1187
- Integrated approach
- Learn through examples
- Learn from each other

Part 1.3

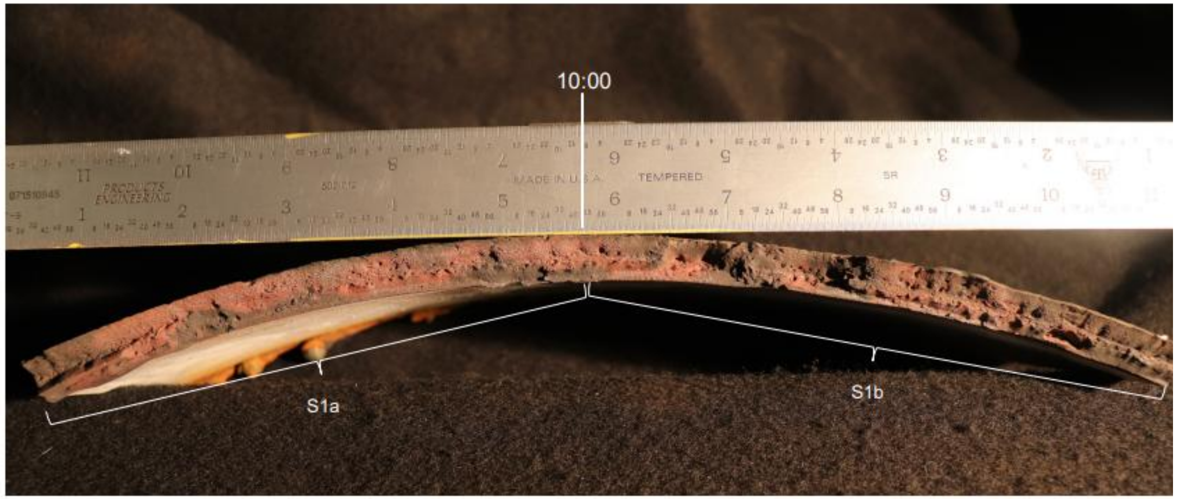
Terms and Concepts

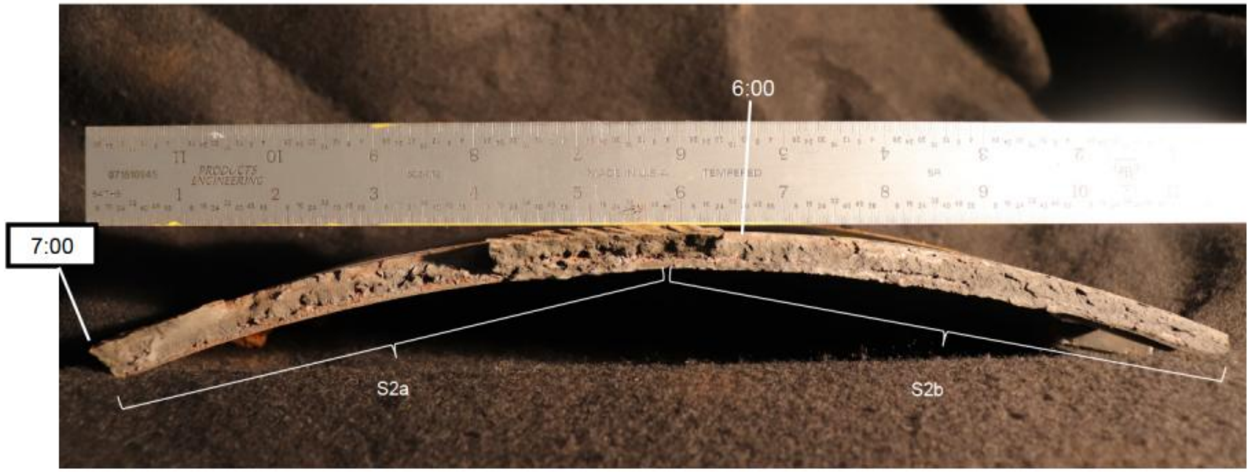
Geohazards - Landslides


Don West, 2006

Doug Dewar 1996

Tensile Rupture at Girth Welds





Source: NTSB Investigation Number: PLD20LR001

Compressive Buckling

Conditions for a Failure or an Incident

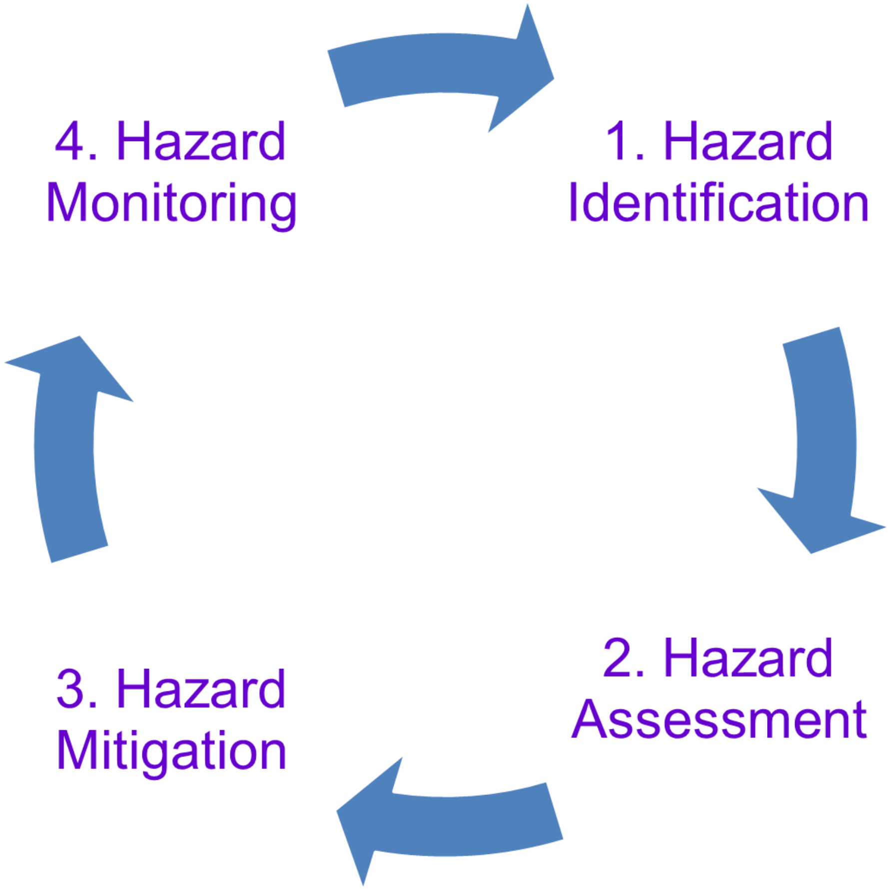
- The terms "incident" and "failure" are treated interchangeably.
- Capacity is the maximum level of stress/strain a pipeline could sustain before an undesirable event, such as a leak or rupture.
- Demand is the stress/strain imposed on the pipeline by its operational and surrounding/supporting conditions.
- Failure or incident from integrity viewpoint
  - Demand > Capacity

Terms in API RP 1187

- Geohazard
  - Hazard caused by ground movement or flowing water that occurs at discrete locations and may threaten the integrity of a pipeline or associated facility.
- Geotechnical hazard
  - *Threat* to a pipeline that results from displacement of soil or rock. This group of hazards includes landslide, subsidence, seismic, heave, and volcanic events
- It appears that "hazard" and "threat" is treated interchangeably.
- "Landslide threat management measures are a component of general preventative and mitigative measures."
  - Preventative and mitigative measures: Activities designed to reduce the likelihood of a pipeline failure or minimize or eliminate the consequences of a pipeline failure

"Traditional" Geohazards Management

- Focus on the detection, characterization, mitigation, and monitoring of hazards
- Mitigation decisions are made based on the characteristics of hazards.
- The varying level of strain tolerance of pipelines is given a limited or no consideration.



Don West, Golder

Geohazards Management - Moving towards Integration

- Almost exclusively based on hazards
  - Mitigation decisions are mostly based on the characterization of hazards and their confirmed or projected impact on a pipeline (i.e., pipeline being "engaged").

Past, Current

- Focusing on hazards with some considerations of capacity
  - Capacity may be grouped by vintage and construction methods.
  - Severity of hazards, including its impact on a pipeline, is ranked.
  - Mitigation decisions is based on ranking system of demand and capacity

Current

- Holistic, or integrity-centric
  - Equal focus on demand and capacity
  - Quantitative determination of safety margin (capacity – demand)
  - Mitigation decisions based on safety margin

Future, Current

Advantages of Integrity-Centric Approach

- Only do what is needed
- Understand current and future safety margin
- Better understanding of the risk level associated with mitigation decisions
- Likely more cost-effective in the long term than looking at one side of the safety margin.
- Approach consistent with how other hazards are managed.

Part 2.1

Introduction of API 1187

Incentive for Proactive Geohazards Management

- Geohazards have been increasingly recognized as a pipeline integrity concern in 2010s and early 2020s
- PHMSA advisories on geotechnical and hydrotechnical hazards
  - Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by **Earth Movement and Other Geological Hazards**, 87 Fed. Reg. 33,576 (June 2, 2022).
  - Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by **Earth Movement and Other Geological Hazards**, 84 Fed. Reg. 18,919 (May 2, 2019).
  - Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by **Flooding, River Scour, and River Channel Migration**, 84 Fed. Reg. 14,715 (April 11, 2019).
  - Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by **Flooding, River Scour, and River Channel Migration**, 81 Fed. Reg. 2,943 (January 19,2016).

Incentive for Proactive Geohazards Management

- Increasing recognition that geohazards could be proactively identifiable and managed
  - ISO 20074 (2019)
  - Operators in-house geohazard management programs
- Regulations
  - No framework
  - Performance requirements: operators were expected to manage geohazards without specific requirements
- Some industry RPs and standards emerged, but not for geohazards management
  - API RP 1133 (hydrotechnical hazards – 2017)
  - ISO 20074 (Petroleum and natural gas industry — Pipeline transportation systems — Geological hazard risk management for onshore pipeline; 2019)

Incentive for Proactive Geohazards Management

- Some Industry guidance documents on geohazards emerged
  - Guidelines for Constructing Natural Gas and Liquid Hydrocarbon Pipelines Through Areas Prone to Landslide and Subsidence Hazards (2009; PRCI)
  - Pipeline Seismic Design and Assessment Guideline (2017; PRCI)
  - Management of Ground Movement Hazards for Pipelines (2017; CRES led JIP – later published by INGAA Foundation)
  - Guidelines for Management of Geohazards Affecting the Engineering and Construction of New Oil and Natural Gas Pipelines (2018; PRCI)
  - Pipeline Geohazards: Planning, Design, Construction, and Operations (2019; Rizkalla and Read [Eds])
  - Pipeline Integrity Management under Geohazards Conditions, 2020, ASME book, Salama, et al. eds
  - Guidelines for Management of Landslide Hazards for Pipelines (2020; led by Geosyntec and CRES, INGAA Foundation)

History of API RP 1187

- In early 2020s INGAA Foundation and API discussed creating a new RP as an industry standard.
- INGAA Foundation formed a JIP and solicited proposals in early 2022 to write the base document.
- The proposal jointly submitted by Geosyntec and CRES was selected.

History of API RP 1187

- Two work packages (WPs) in INGAA JIP
- WP 1 Framework for Geohazard Management (2023)
  - In addition to develop the framework, the following issues were targeted:
    - ►Broad range of geohazards or something specific for the RP?
    - ►Review of US and European data concluded that most geohazard LOC events are from landslides
    - ►There was existing guidance for hydrotechnical (API RP 1133) and seismic (PRCI guidelines) hazards
    - ►Landslides were selected as the target for the RP.
- WP 2 Management of landslides
  - Become a base document for API RP 1187

History of API RP 1187

- Objectives of the JIP
  - Rapid completion (1 year from proposal to publication)
  - Framework document incorporating input and practices from participating companies

- INGAA Foundation JIP Members:
  - Boardwalk Pipelines
  - Cheniere
  - Enbridge (JIP Lead)
  - Equitrans
  - Kinder Morgan
  - Marathon
  - National Fuel
  - Pacific Gas & Electric
  - SoCalGas
  - TC Energy
  - Williams

History of API RP 1187

- Strategic decisions
  - Focus on process over prescriptive requirements
  - Concise and accessible to non-geohazard specialists
  - Develop common framework and terminology between pipeline integrity specialists and geohazard specialists
  - Encourage general adoption of proactive assessment of pipeline systems for landslide hazards

API RP 1187 Features

- Few prescriptive requirements except that users should assess their systems for landslides
- Presents leveled assessment process
- Short, process-focused standard on identification, assessment, and management of landslide hazards for existing pipelines
- Assumes user can reference other documents for details
- The document is structured with a hazards focus, incorporated integrity assessment.
  - Process to integrate hazards assessment vs. integrity assessment can be further developed in the future.

API RP 1187 – Main Body

1. Scope
2. Normative References
3. Terms, Definitions, Acronyms and Abbreviations
4. Landslide Management Program
5. Landslide Threat and Integrity Assessment
6. Data Management
7. Threat Management
8. Program Evaluation
9. Management of Change

API RP 1187 - Annexes

Annex A: Landslide Basics

Annex B: Geologic and Geotechnical Assessment of Landslides

Annex C: Fitness-for-Service Assessment in Landslide Management

Annex D: Landslide Assessment Examples

Annex E: Data Management

Annex F: Classification and Decision-Making Programs

Annex G: Landslide Threat Management Measures

Annex H: Landslide Program Evaluation Metrics

Annex I: Interacting Threats in Landslide Management

API RP 1187 – High-Level Closure

- API RP 1187
  - Provides a structured, systematic process for managing landslides consistent with industry practice
  - Covers major components of identification, assessment, and threat management of landslide hazards
  - Promotes the integration of hazards and integrity assessments
  - Not perfect, room to improve
- No "one size fits all" in managing landslides
  - Each company should have a program that suits its needs and circumstances.
  - The most effective program is the one that considers the characteristics of both hazards and pipelines
- Annex D examples are a good starting point for newcomers.

Part 2.2

Geohazards Management

Section 4 Landslide Management Program

- *Objective: minimize the likelihood of landslide hazards causing undesirable consequences to a pipeline, such as a leak, rupture, or impaired serviceability*
- Overview of program
- Key components (further covered in Sections 5 – 9)
- Program should be administered by a designated group
- Program should be documented
- General considerations
  - Characteristics of landslide
    - Should consider elements unique to landslides, such as large range in rate of movement of landslides.
  - ILI
  - Capacity of pipelines can vary significantly

Section 5 Landslide Threat and Integrity Assessment

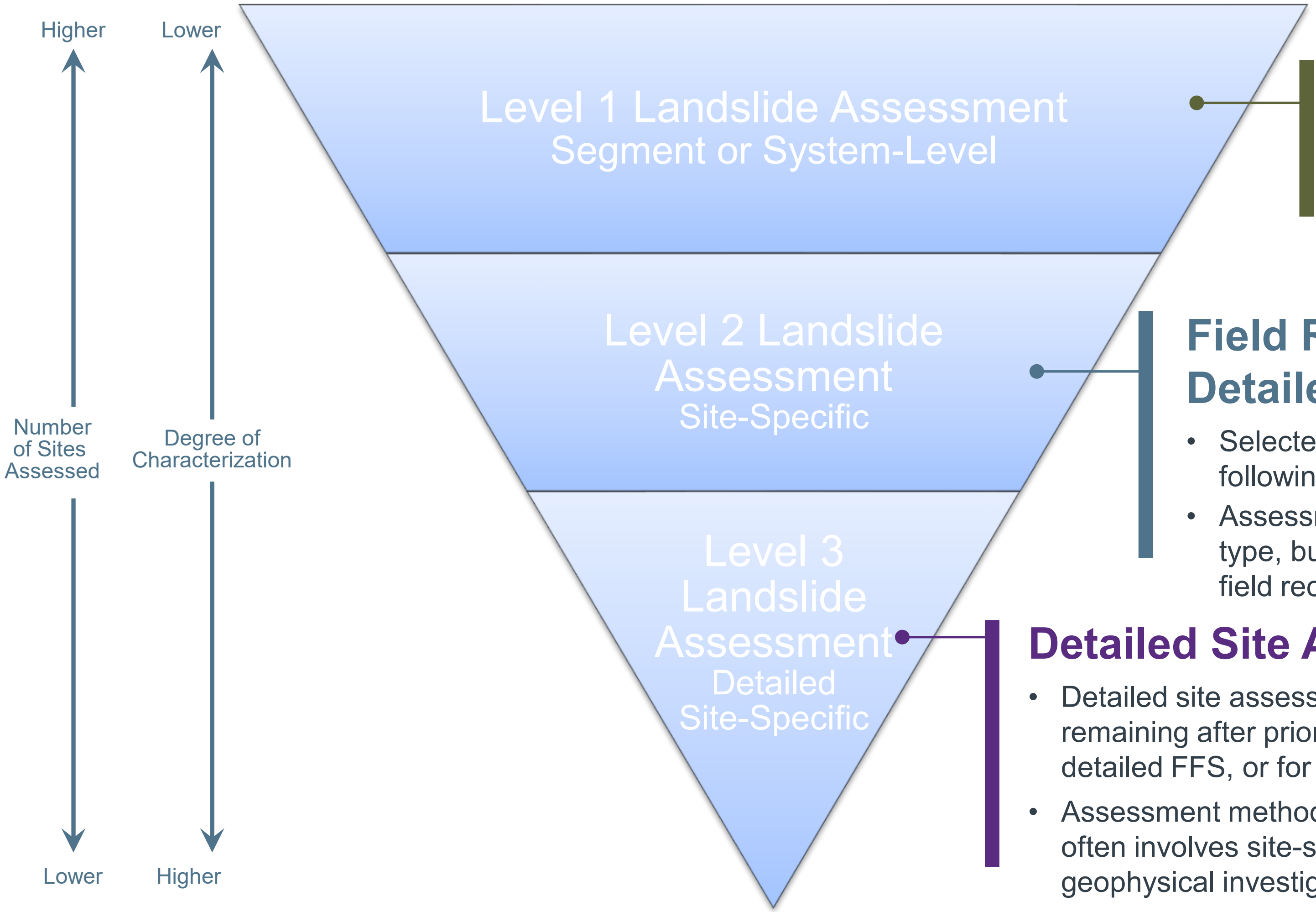
- Landslide is a major threat to pipeline integrity.
- Threat
  - Is not the same as an incident.
  - Does not necessarily lead to an incident
- Threat management
  - To prevent occurrence of incidents
- Details are supported by Annex A, Annex B

- Most of the language is written for "threat assessment" in Section 5.

Section 5 Landslide Threat and Integrity Assessment

Threat identification and assessment through a 3-level approach.

Systematic approach in which the degree of characterization of an individual landslide is commensurate with the level of effort needed to establish the threat to a pipeline and determine appropriate response actions.



Desktop Review

- Preliminary threat characterization
- Can be considered a screening level assessment

Field Reconnaissance or Detailed Desktop

- Selected sites further characterized following Level 1 or monitoring results
- Assessment methods vary by hazard type, but usually involves non-intrusive field reconnaissance

Detailed Site Assessment

- Detailed site assessment to resolve uncertainties remaining after prior levels, to collect information for detailed FFS, or for mitigation measure design
- Assessment methods vary by hazard type, but often involves site-specific geotechnical or geophysical investigations

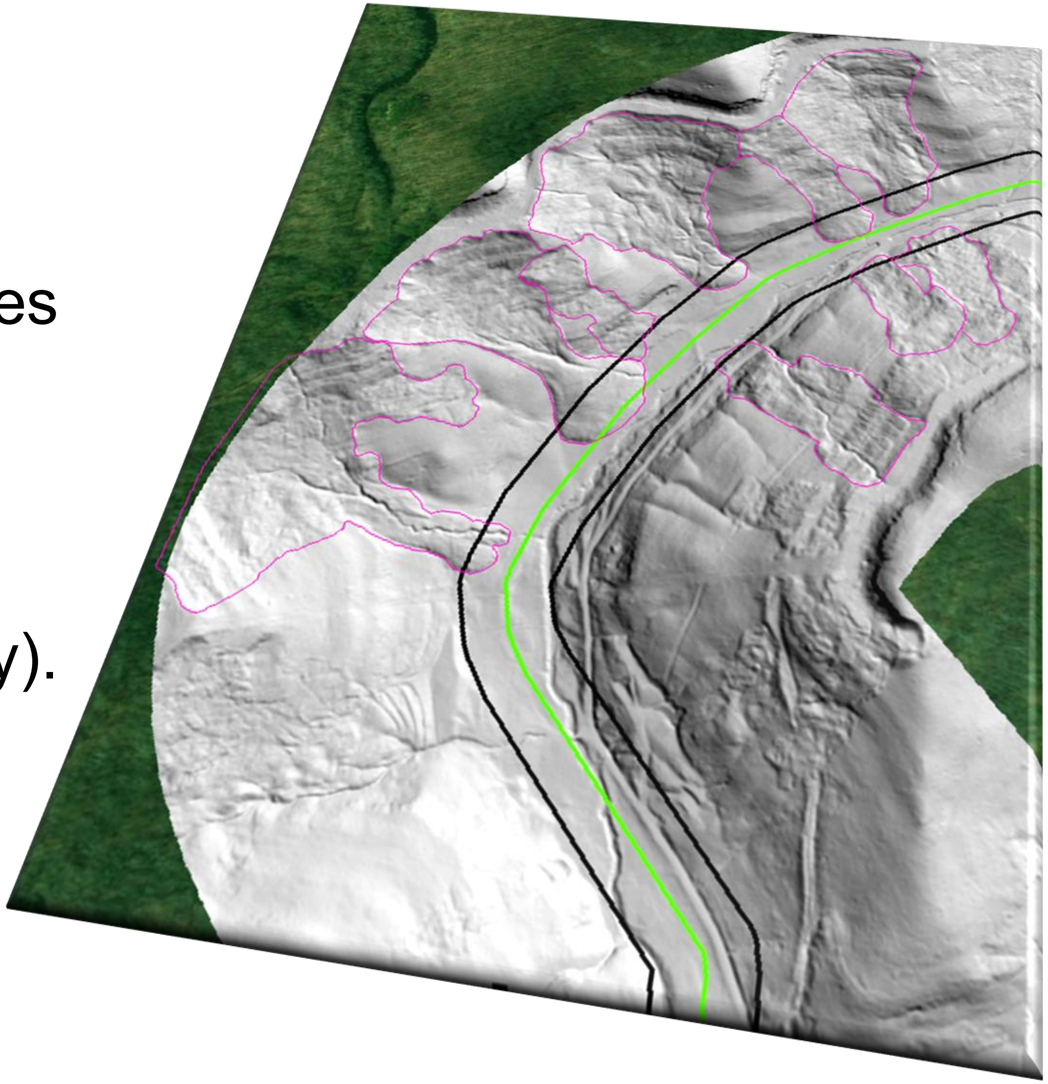
Multi-Level Characterization of Hazards

- Level 1 – desktop
  - Available topographic, geologic, and remote sensing data
  - Operator experience
  - Aerial reconnaissance
  - Classify threat level and consequence
  - Results entered into GIS for further assessment
- Level 2 – site-specific, non-intrusive
  - Geomorphic and geologic reconnaissance
  - More accurate cite-specific assessment than Level 1
  - Update GIS
- Level 3 – site-specific, intrusive
  - Surface and sub-surface geologic and geotechnical hazards characterization
  - Support quantitative assessment, mitigation, and monitoring

Landslide and Integrity Assessment

Level 1 Landslide Assessment - Objectives

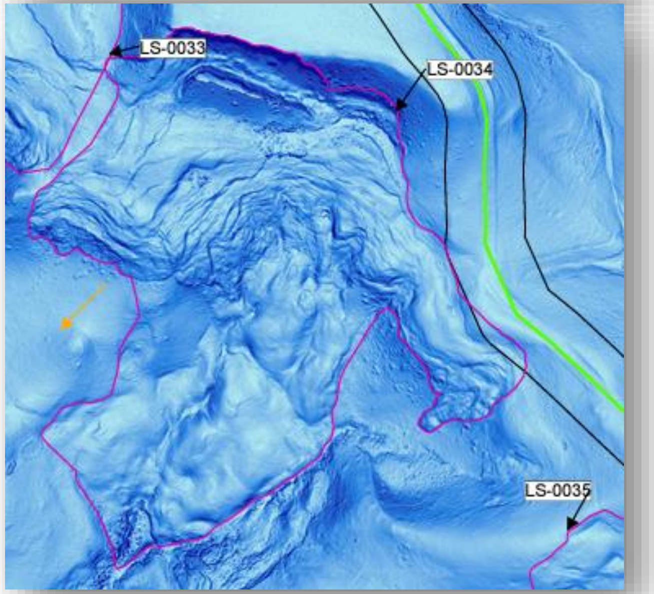
- Develop an inventory of the possible landslide(s) along the pipeline
- Initially evaluate the threat each landslide poses to adjacent pipeline(s)
- Initially evaluate the availability of data/information necessary to assess the resilience of a pipeline (such as strain capacity).



Landslide and Integrity Assessment

Level 1 Landslide Assessment - Approach

- ❑ Where?
  - ❖ Everywhere
- ❑ What?
  - ❖ Desktop review of LiDAR, aerial photographs, or aerial reconnaissance.
  - ❖ Identify, map, and document landslide activity within at least 100 feet of a pipeline centerline in a geographic information system (GIS).
  - ❖ Review existing information, such as ILI results, pipeline resiliency, or locations of known landslides and prior repairs.



Landslide and Integrity Assessment

Level 2 Landslide Assessment - Objectives

- Confirm whether landslides and potential landslides identified during a Level 1 Assessment are indeed landslides and whether the landslides impact the pipeline(s).
- Gain a better understanding of the characteristics of the landslides and potential threats posed to a pipeline(s) to support decision-making.
- Provide further information needed to support an FFS assessment.
- Reassess a previously evaluated landslide when changes might have occurred, such as identification of movement or changes in pipeline strain from ongoing monitoring. Based on reevaluation, determine if and what additional actions are needed.

Landslide and Integrity Assessment

Level 2 Landslide Assessment - Approach

- ❑ Where?
  - ❖ Level 1 results determine which sites require Level 2
- ❑ What?
  - ❖ Site-specific investigation focused on specific, identified landslides
    - ►A field reconnaissance, including locating the pipeline.
    - ►A detailed records review or detailed desktop assessment or analysis (e.g., review construction records or mitigation design).
    - ►An initial FFS assessment, including strain capacity and strain demand from one or more sources with available data

Landslide and Integrity Assessment

Level 3 Landslide Assessment - Objectives

- Resolve or reduce uncertainties remaining from prior assessments regarding the impact of a landslide on a pipeline.
- Acquire additional information or perform analyses needed to make or implement a risk-management decision.

Landslide and Integrity Assessment

Level 3 Landslide Assessment - Approach

- ❑ Where?
  - ❖ Level 2 results determine which sites require Level 3
- ❑ What?
  - ❖ Detailed site-specific investigation
  - ❖ Methods are fit-for-purpose, and may include:
    - ►A detailed assessment of the subsurface conditions (e.g., geotechnical boreholes, test pits, installation of SIs)
    - ►An FFS assessment that may include the current state of the pipeline and/or expected future increase in strain demand and possible degradation of strain capacity

Section 5 Landslide Threat and Integrity Assessment

Overall Recommendations

- A Level 1 Landslide Assessment (desktop) should be conducted for the entirety of a pipeline operator's system(s).
- Geomorphic assessment of the landslide hazard should be integrated with pipeline integrity assessment (i.e., the impacts of the landslide on the pipeline and the ability of the pipeline to withstand that impact).
- ILI information should be integrated with the geomorphic assessment where available.

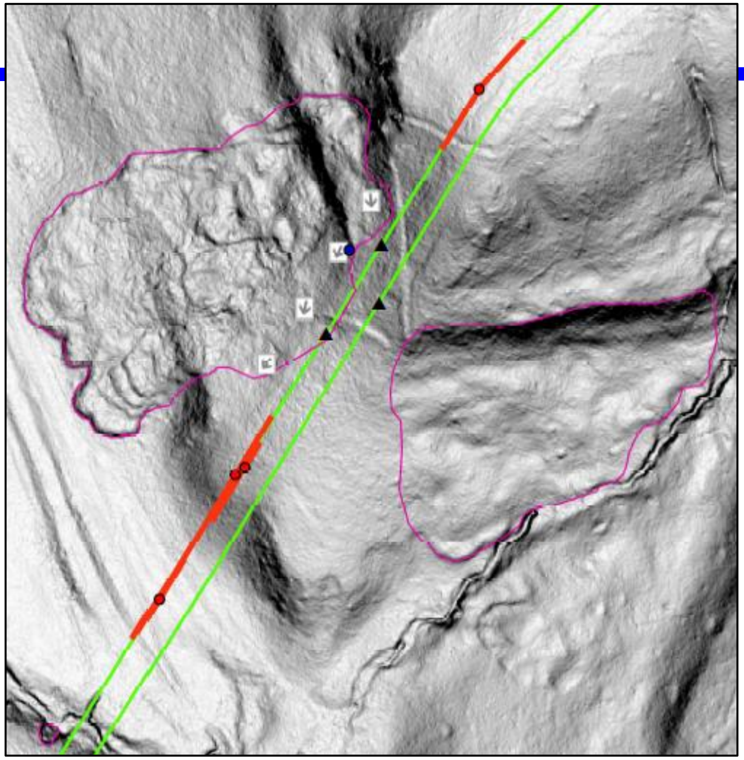
Section 5 Landslide Threat and Integrity Assessment

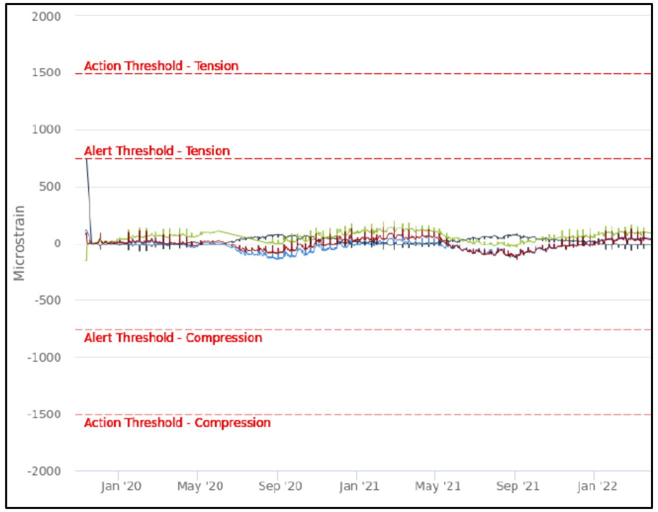
Overall Recommendations

- The assessment should only proceed as far as needed to determine an appropriate response.
  - Most identified landslide hazards will not proceed past Level 1 and relatively few should progress to Level 3.
- An updated Level 1 Landslide Assessment should periodically be performed to account for changed conditions and advances in technology and information. The RP recommends 10-year intervals or less.

Section 6 Data Management - Hazards

- Details are supported by Annex E.
- Program should have an efficient mechanism in place to sort, store, and integrate data as they are generated and to retrieve data as they are needed.
- Spatial Data (map): should be managed in a GIS platform (i.e., a map-based platform such as ESRI ArcGIS, QGIS, or Google Earth) where dimensional aspects of the data can be viewed and accessed.
  - Landslide boundary, pipeline centerlines, monitoring instrument locations, IMU bending strain features, etc.
- Non-Spatial Data: organized & linked to spatial data
  - Monitoring results (time-series), photographs, as-builts, geotechnical information, etc.





Section 6 Data Management - Pipeline

- Pipeline characteristics
  - OD, WT, Grade
- Construction
  - Construction year
  - As-built details
  - Field welding, inspection, and flaw acceptance
- Pipeline operating conditions
- Failure history, if any
- ILI of anomalies

Section 7 Threat Management

Details are supported by Annex F and Annex G.

Classification and decision-making (CDM) system – an approach to classify landslide threats, to determine:

1. Whether to perform additional assessment (e.g., Level 2 or 3) or implement a threat management action
2. The nature of that action
3. The timing or order of conducting actions (i.e., the prioritization)

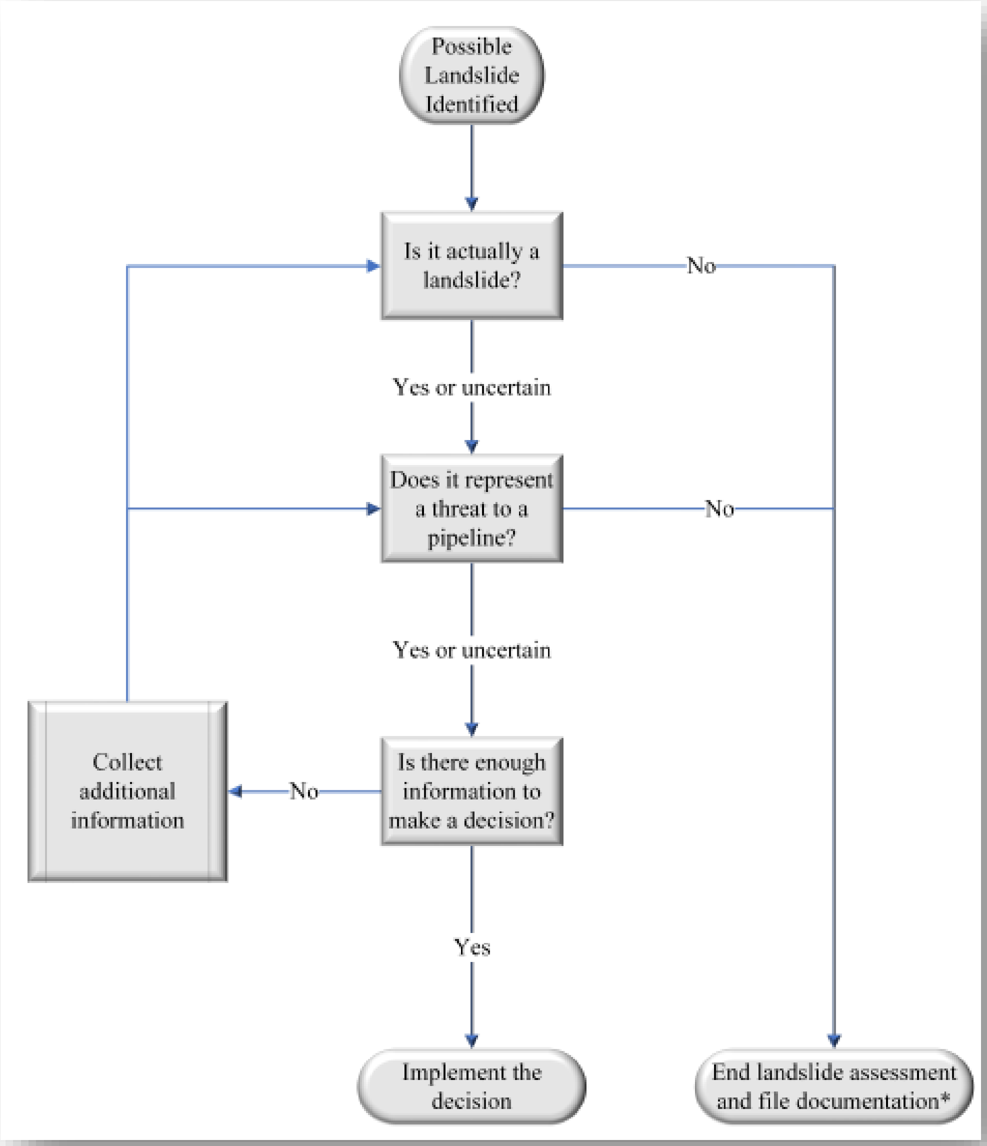


Figure F.1—CDM Flowchart for Newly Identified Possible Landslides

Section 7 Threat Management

- Threat management measures
  - Monitoring
  - Mitigation
- Mitigation
  - Reduce demand
  - Enhance capacity

Section 8 Program Evaluation

- Recommends that operators follow the general structure of API RP 1160, Section 13, for evaluation of their landslide management program.
- Evaluation should periodically be performed to assess the effectiveness and completeness of the landslide management program.
- Landslide-specific metrics are provided in Annex H.

Section 9 Management of Change

- Recommends that operators develop a MOC process for their landslide management program that addresses the following:
  - New construction
  - Acquisition of a pipeline system
  - Major operational changes
    - Pressure
    - Product
    - Flow direction
  - Changes in pipeline status
  - Third-party changes to land use

Part 2.3

Integrated Approach

Details are supported in Annex C.

Part 2.3.1

Why Integrated Approach

Delhi CO_2 Pipeline Failure at Satartia, MS, 02/22/2020

- On February 22, 2020, a CO_2 pipeline 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.
- Delhi Pipeline
  - Installed in 2009
  - 24” OD X80 ERW pipes
  - 77 miles
  - CO2 is used for enhanced oil recovery (EOR)

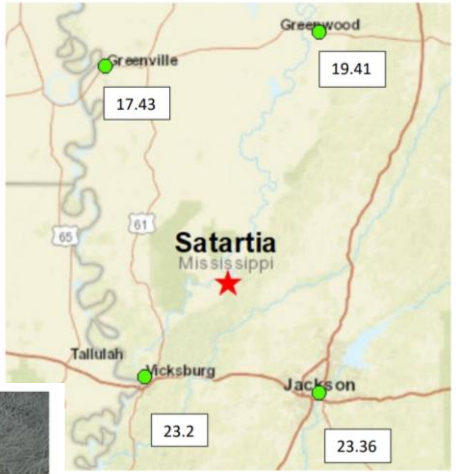


Figure 2: Vehicle is Parked on HWY 433 - The White is Ice Generated by the Release of CO_2 - The Blue Arrow Points North (Aerial Drone Photograph Courtesy of the Mississippi Emergency Management Agency)

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

Delhi CO_2 Pipeline Failure at Satartia, MS, 02/22/2020

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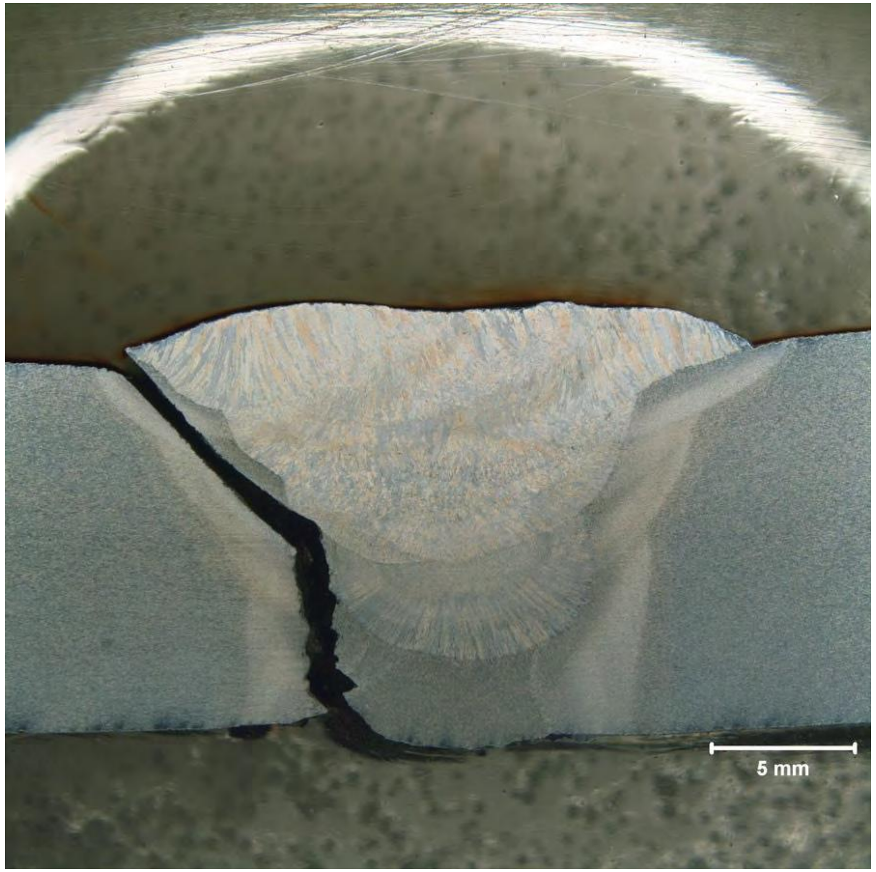


Wesley Mathews, "Failure investigation report – Denbury Gulf Coast Pipelines, LLC – Pipeline Rupture / Natural Force Damage," US DOT PHMSA OPS, May 26, 2022.

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 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
- 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

Figure 2. Cahokia Creek and Mississippi River.


Figure 1.2: Aerial Image of Failure Location

Source: NTSB Docket: PLD22FR002

Woodpat Pipeline Release, 03/11/2022

- Tensile strains were generated from bending of the pipe due to down-slope movement of the soil on the riverbank.
- Previous in-line inspections and field studies had identified movement of the pipeline, erosion, and soil subsidence in the area near the rupture site.

Figure 1.1: Failed Girth Weld During Excavation

Figure 3. IMU data for Woodpat pipeline from 2018 and 2021 and 2022 postaccident GPS survey.

Source: NTSB Number: PLD22FR002

Woodpat Pipeline Release, 03/11/2022

- Flaws on the fracture surfaces of the failed girth weld
  - IP, 7.2-inch long, 1:15 to 1:30 o'clock, shown in figures below
    - ►Metallurgical depth of 7.7mm at deepest point, average 2-4 mm along the length of feature
  - IP, 1.2-inch long, 3:20 to 3:32 o'clock
  - IP, 0.5 inch long, 6:46 to 6:53 o'clock
  - IP, 0.5 inch long, 10:25 to 10:32 o'clock

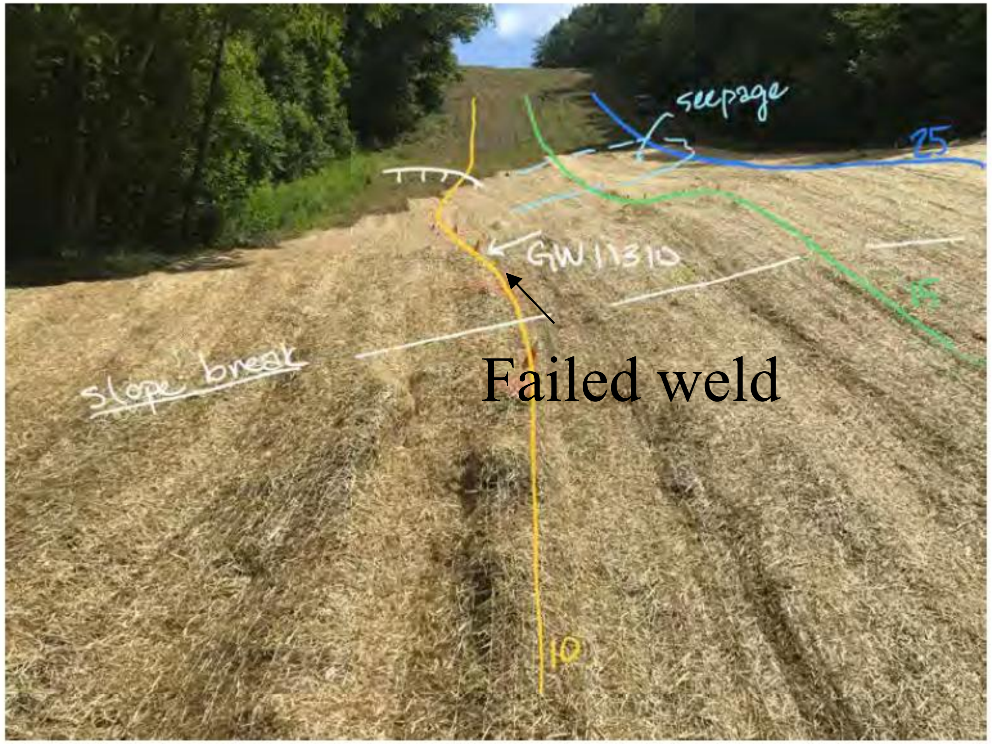
Figure 1: Photograph of fracture surface. Numbered scale divisions are inches.

Figure 2: Photograph of fracture surface.

Source: NTSB Docket: PLD22FR002

Texas Eastern Line 10 Rupture, 05/04/2020

- ❑ Fleming County, Kentucky, May 4, 2020
- ❑ Rupture, fire, no injuries or fatalities



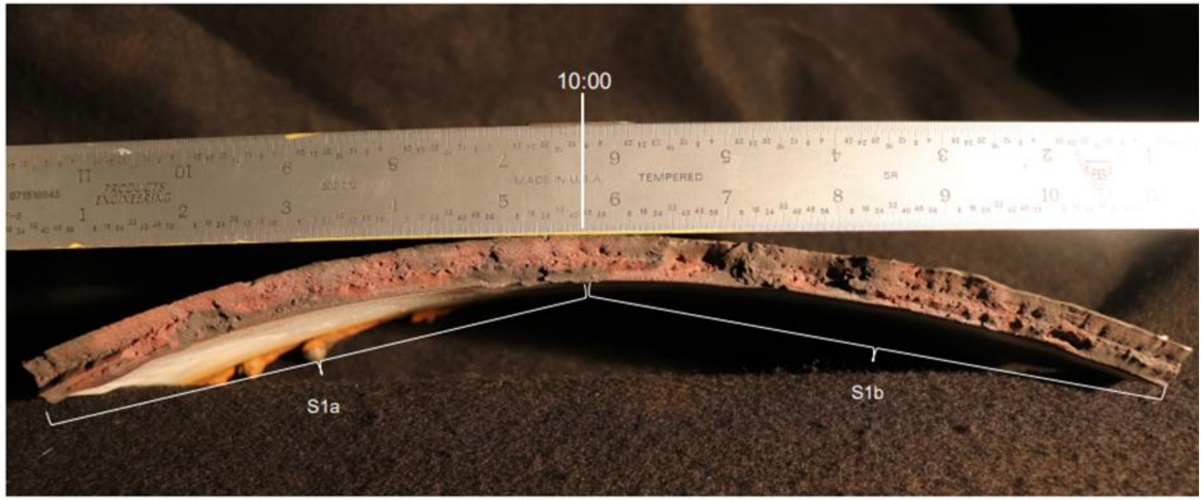
Standing on ROW, looking upslope (NE) at deflected Lines 10 and 15.

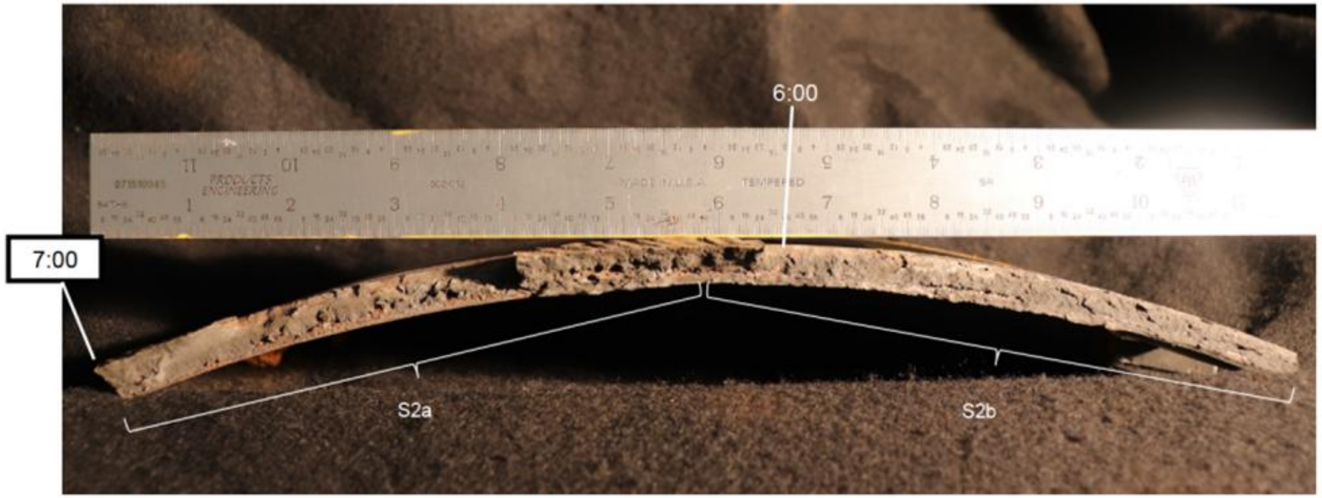
Figure 1. Ruptured pipeline.
(Source: BGC Engineering USA, Inc.)

Source: NTSB Docket PLD20LR001

Texas Eastern Line 10 Rupture, 05/04/2020

- Tensile failure at girth weld followed by weld separation
- Two large flaws (IP/LORF) on the fracture surface of the failed weld
  - 7” x 0.13” (~ 10:00 orientation)
  - 4.9” x 0.1” (~ 6:30 orientation)





Source: NTSB Docket PLD20LR001

Geohazards Do Not Have to Lead to Loss of Containment (LOC)

- ❑ Trans-Alaska pipeline survived a magnitude 7.9 Denali Fault earthquake in November 2002 without loss of containment.
- ❑ ExxonMobil's Papua New Guinea LNG pipeline survived a 7.5 magnitude earthquake in March 2018 without loss of containment.
  - ❖ Strain-based design for fault crossings
  - ❖ Robust stress-based design
  - ❖ Thick wall low grade pipe
  - ❖ Weld strength overmatching and good toughness
- ❑ Success in seismic design in Japan and other countries

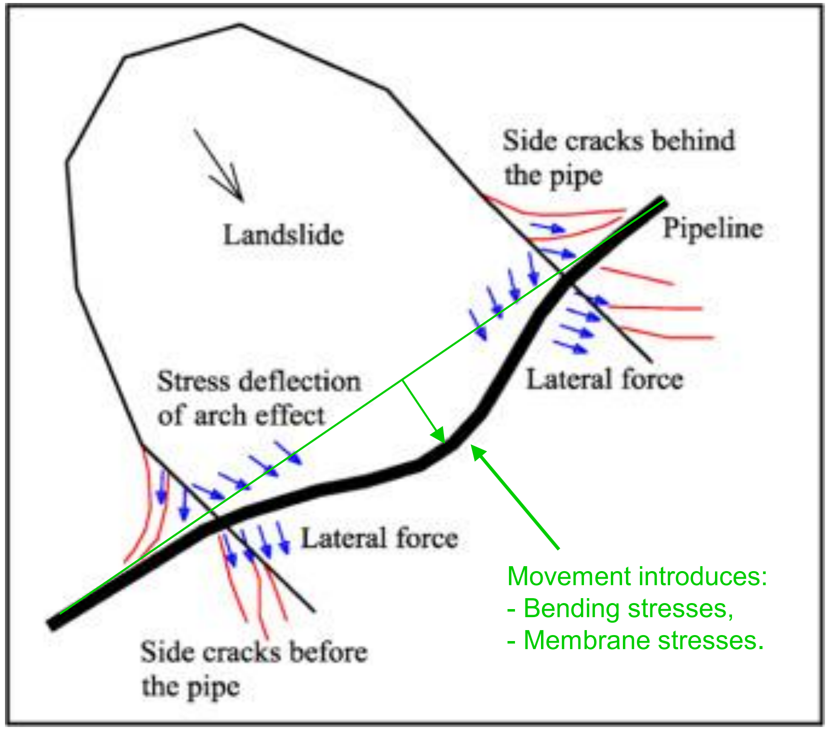
Conditions for a Failure or an Incident

- High demand
  - Hazards impact on pipeline
- Low capacity
  - Vintage pipelines
    - ►Girth weld flaws
  - Modern pipelines
    - ►Weld strength undermatching / HAZ softening
  - Other anomalies
    - ►C-SCC

Part 2.3.2

Strain Demand

Pipeline Being Impacted by a Landslide



Feng, W., et al., Large-Scale Field Trial to Explore Landslide and Pipeline Interaction," The Japanese Geotechnical Society *Soils and Foundations*, Volume 55, Issue 6, December 2015, Pages 1466-1473, Elsevier ScienceDirect

Demand Imposed on a Pipeline is Affected by Nature of Hazards and Pipe Characteristic, and the Interaction between the Two

Doug Dewar, 2003

Part 2.3.3

Tensile Strain Capacity

Girth Welds - Weak Link

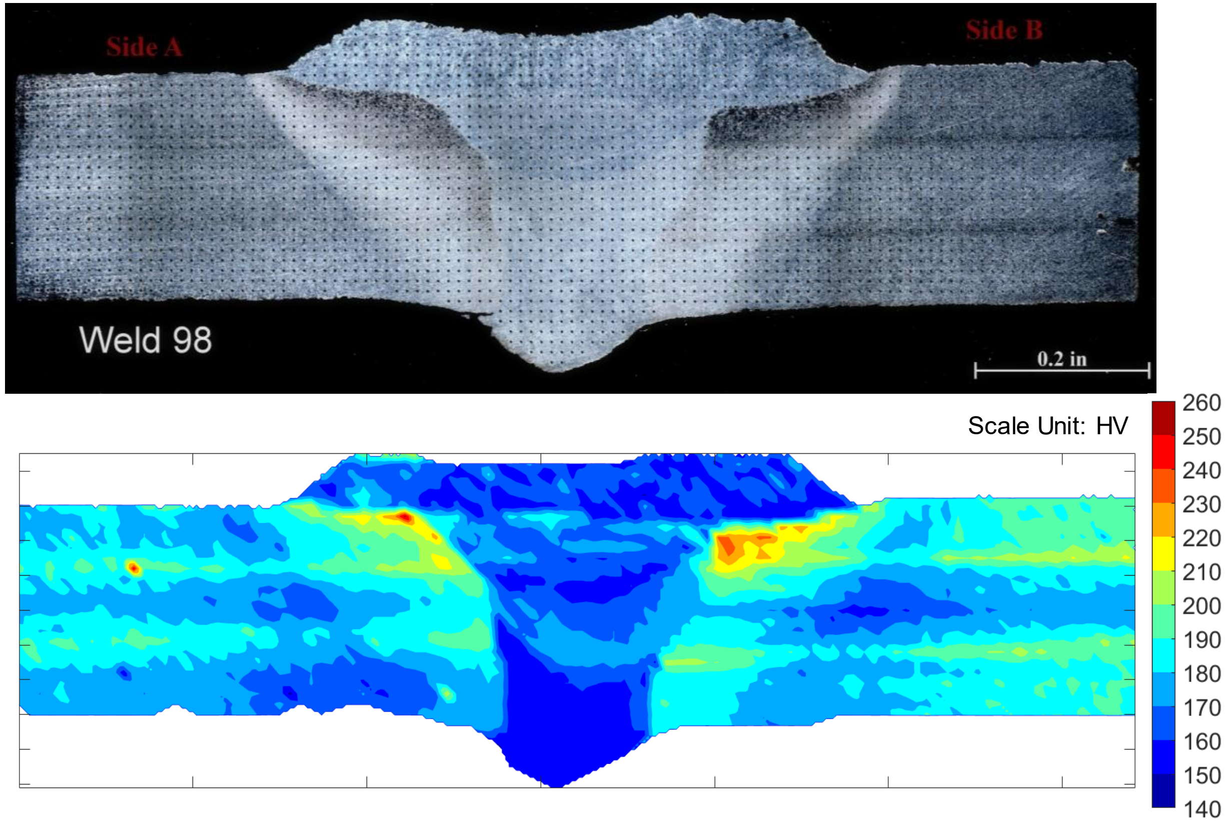
https://www.napipelines.com/prime-connections/

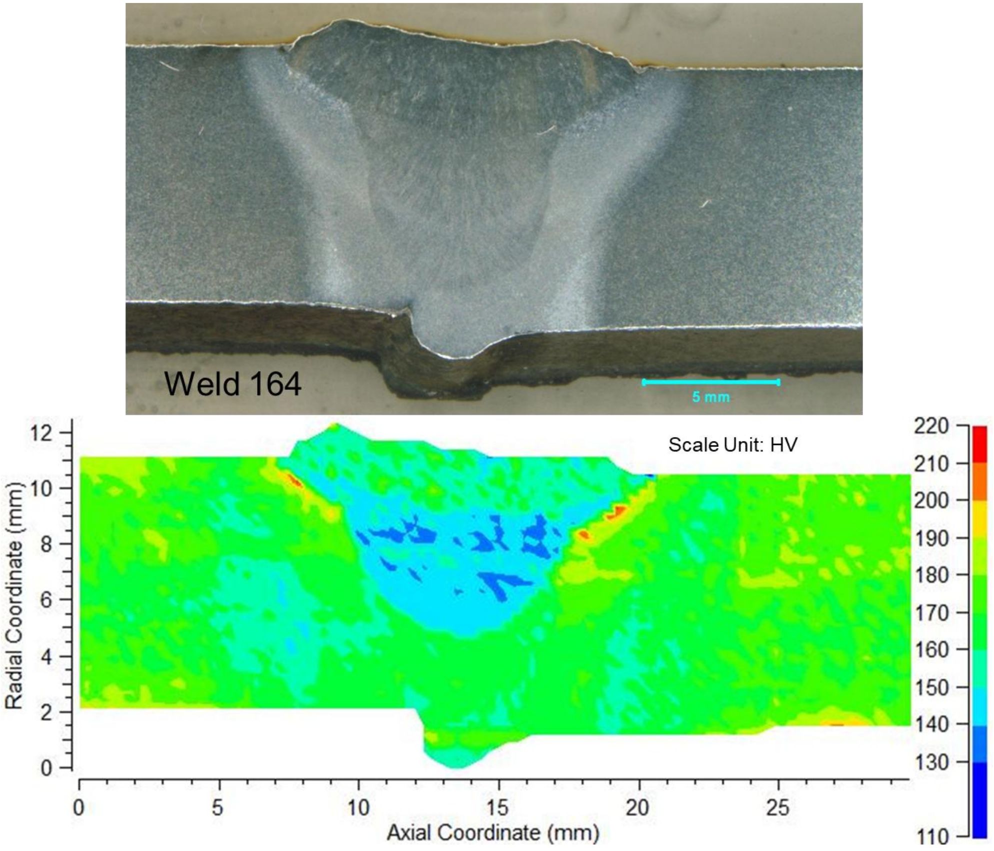
https://www.napipelines.com/prime-connections/

Thermocouples to welding thermal cycle measurement

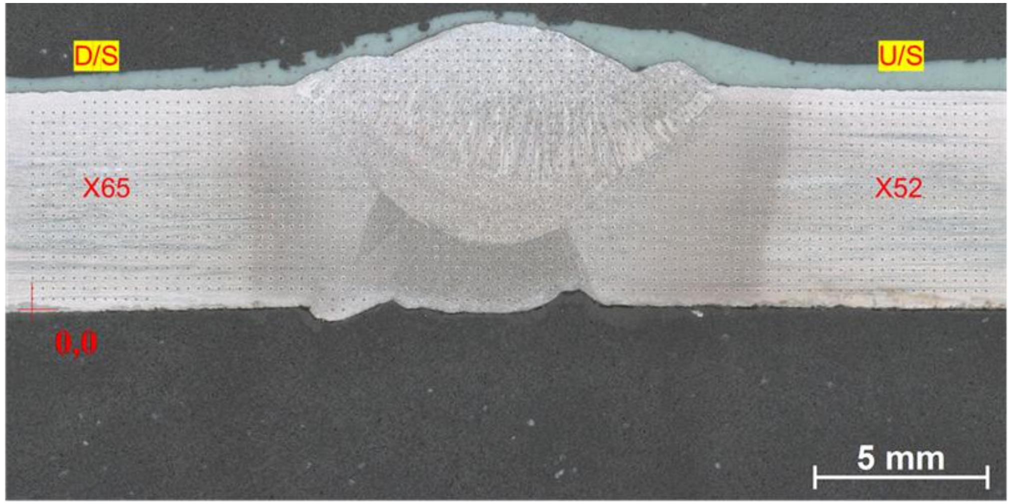
- ❑ Welding thermal cycles changes material properties.

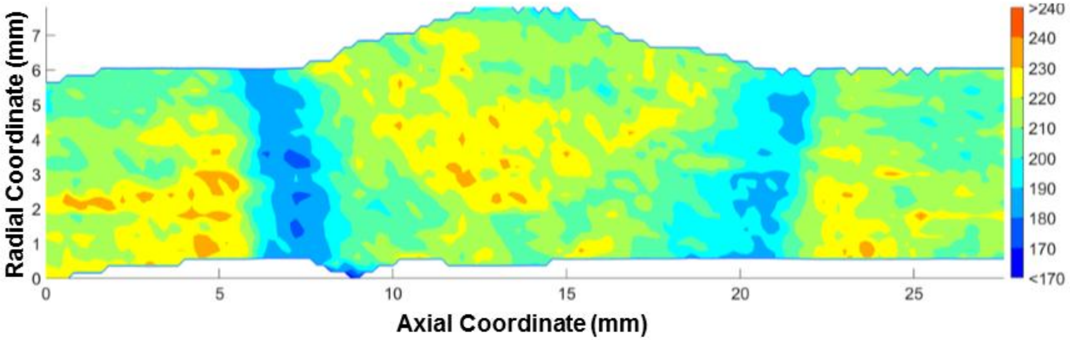
Resulting Girth Weld Properties – Vintage Pipe and GWs

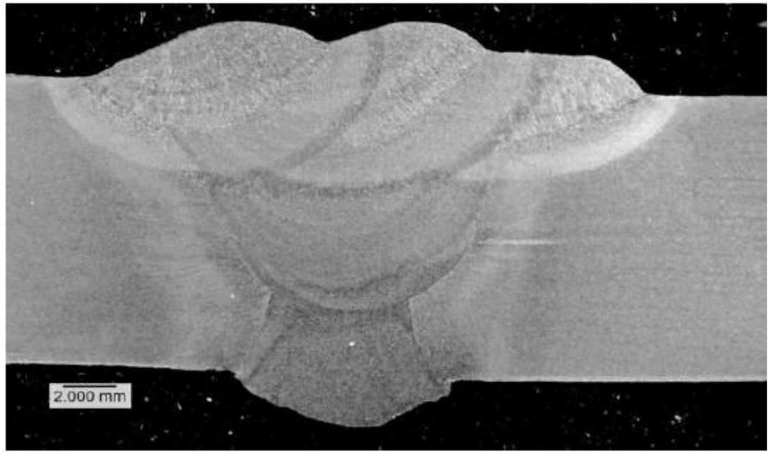


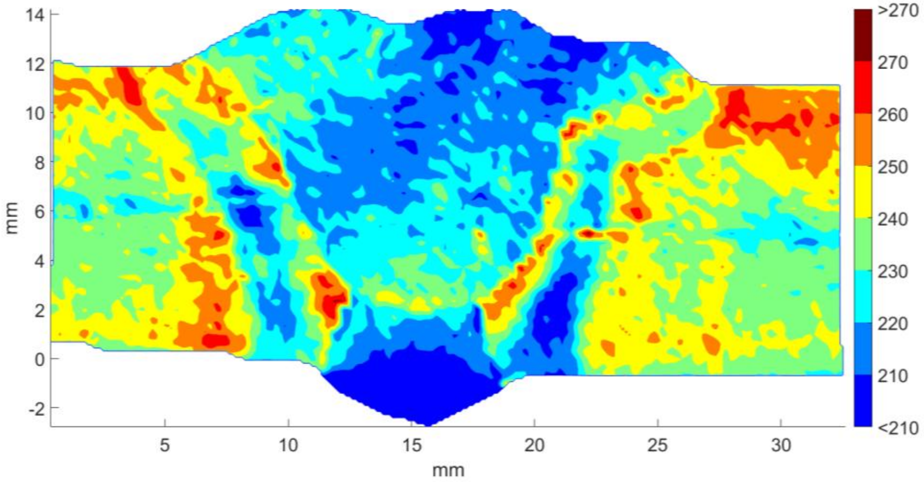


Resulting Girth Weld Properties – Modern Pipe and GWs

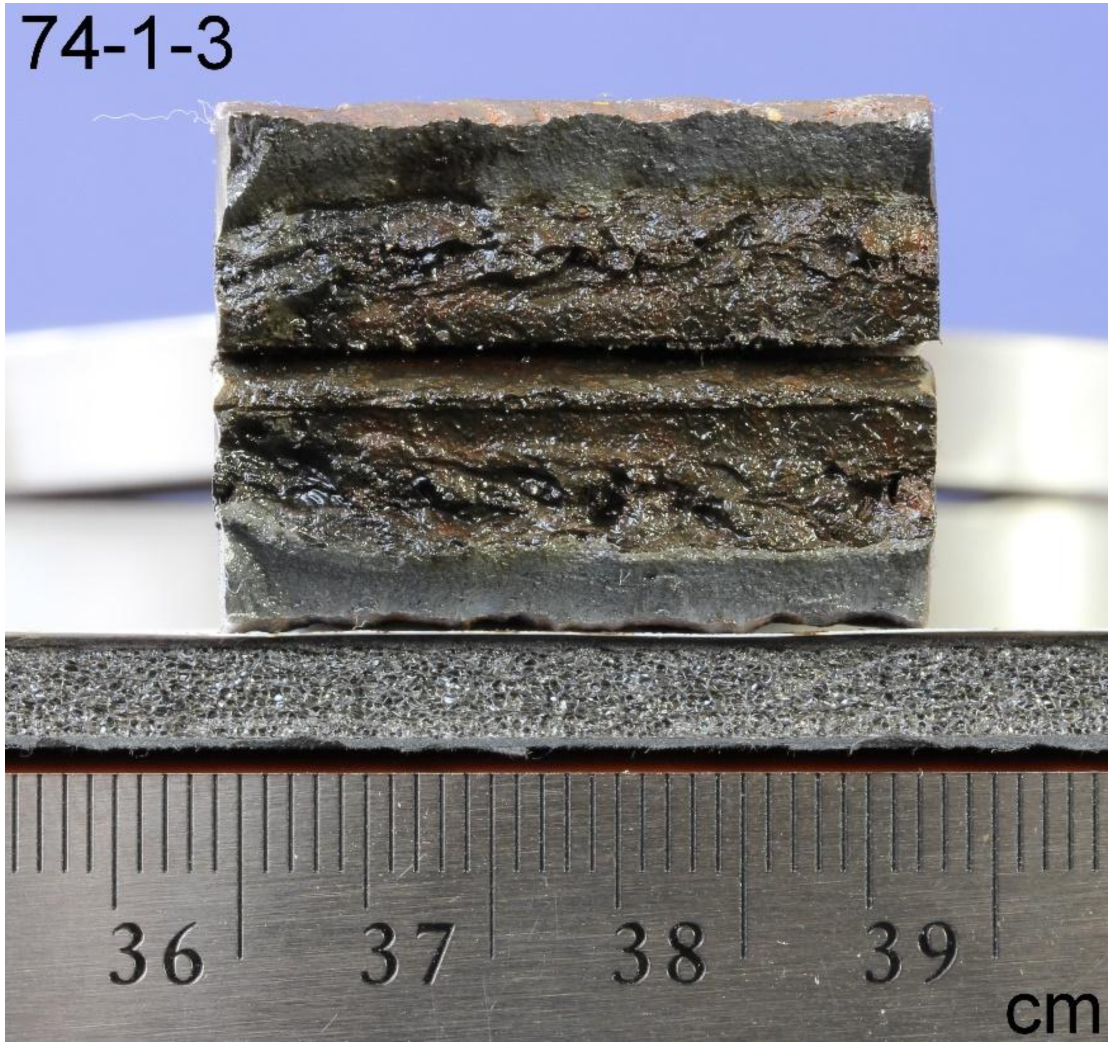


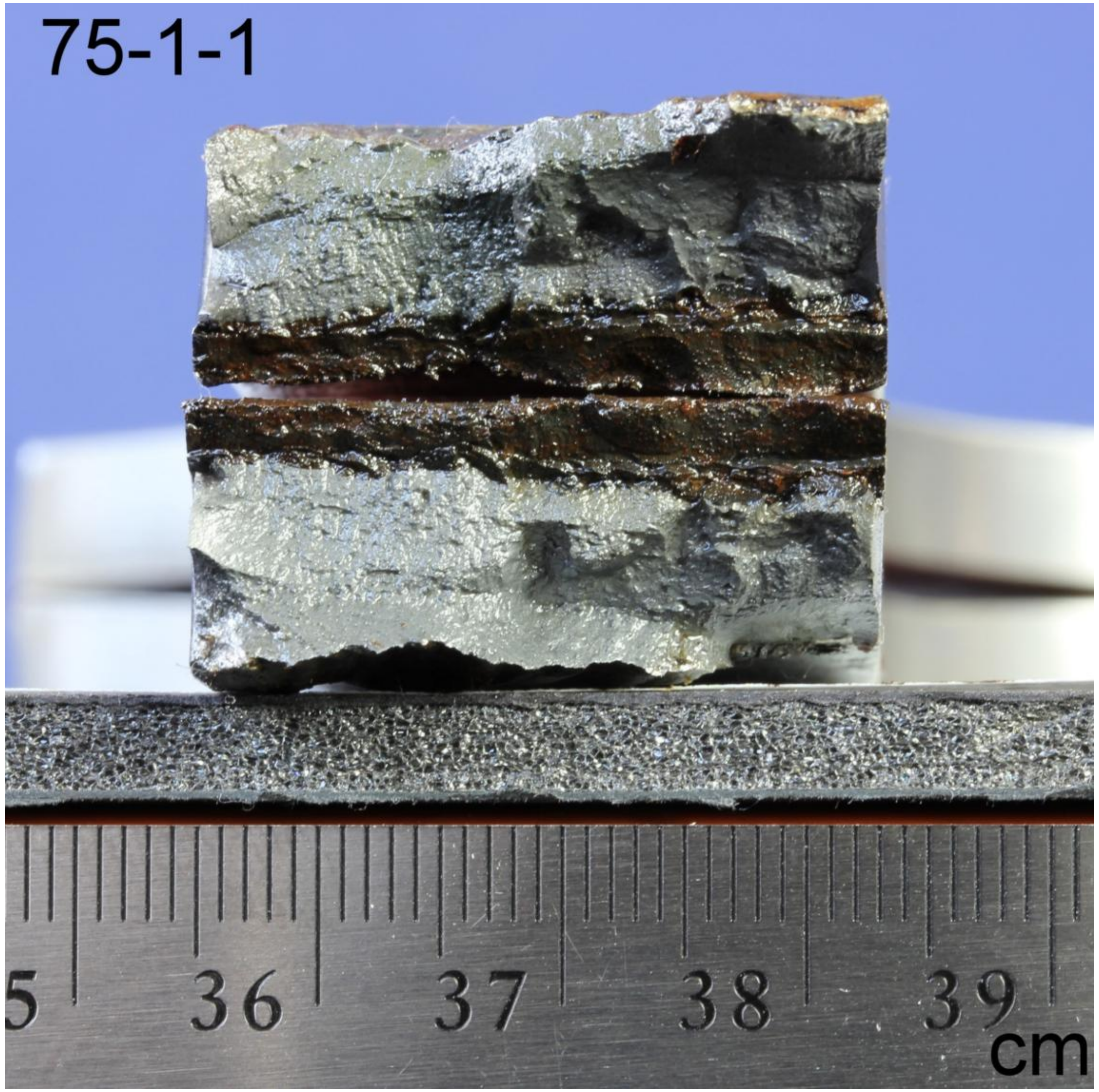




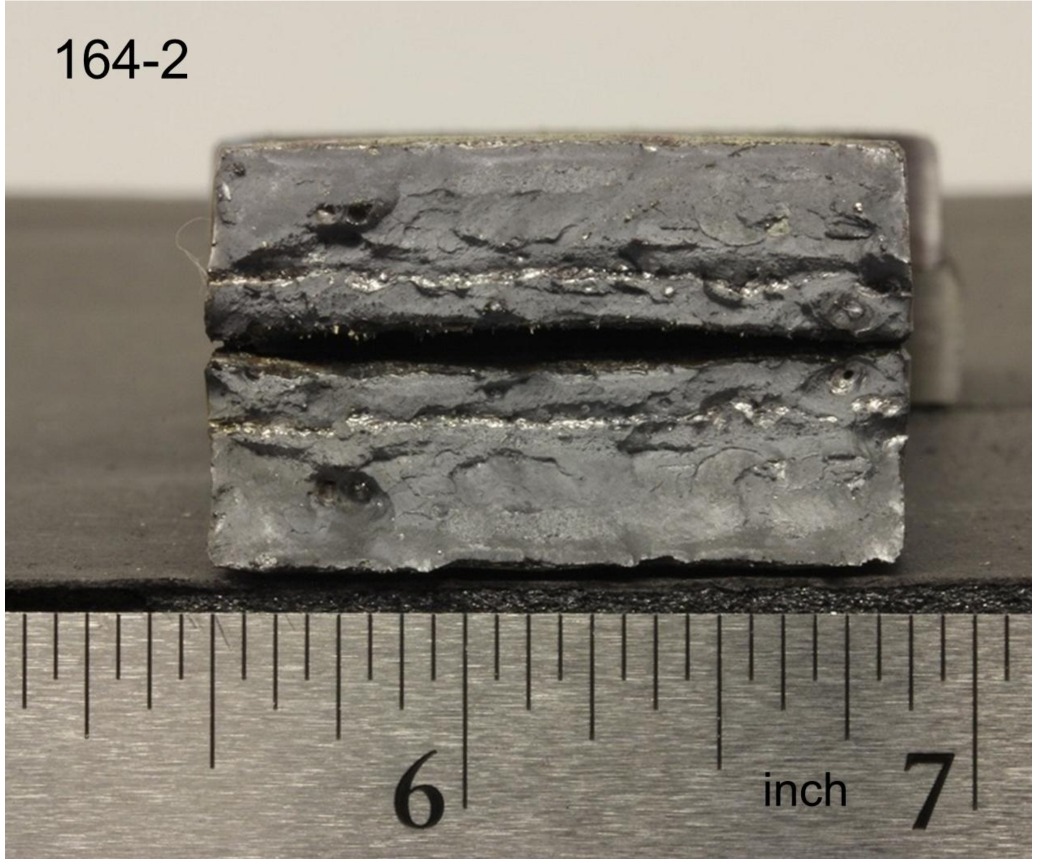


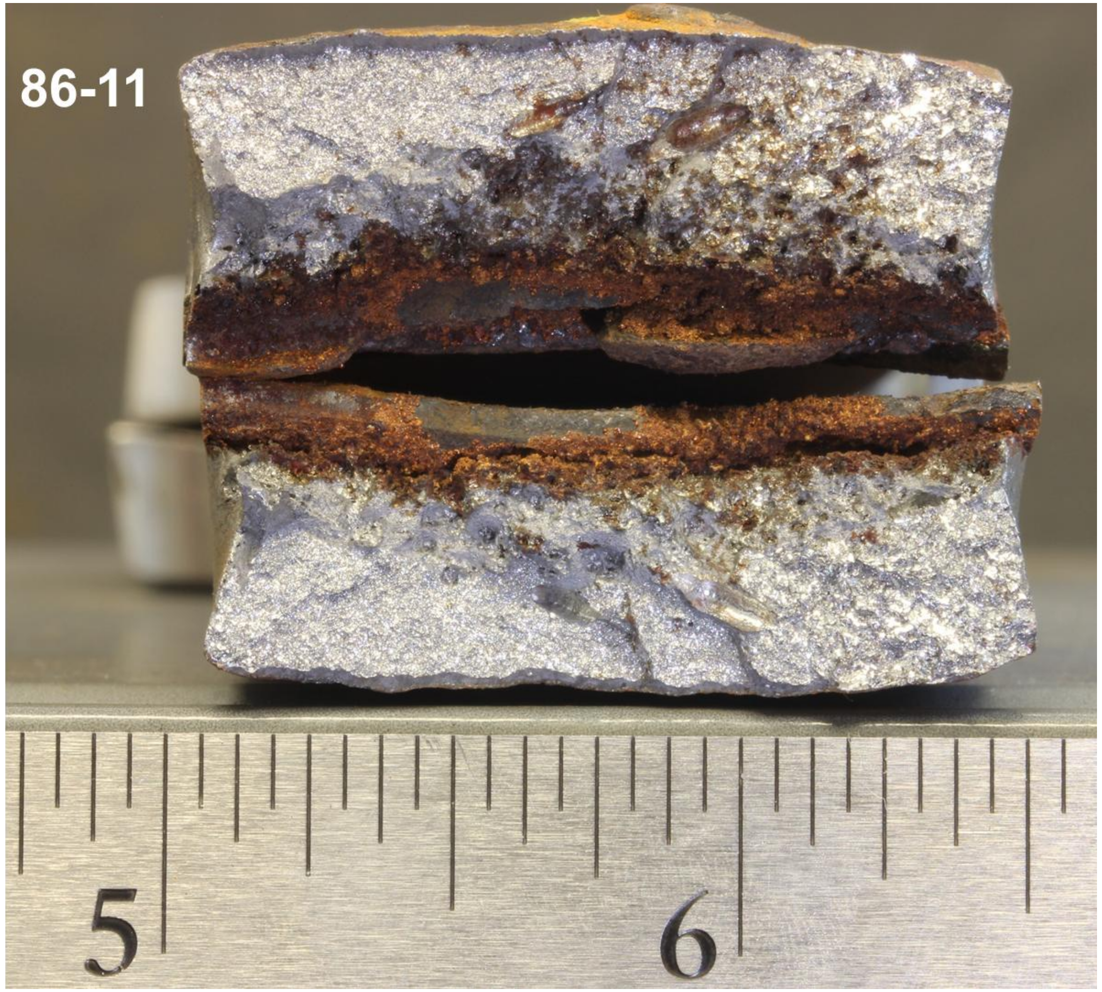
Examples of Girth Weld Flaws in Vintage Pipelines





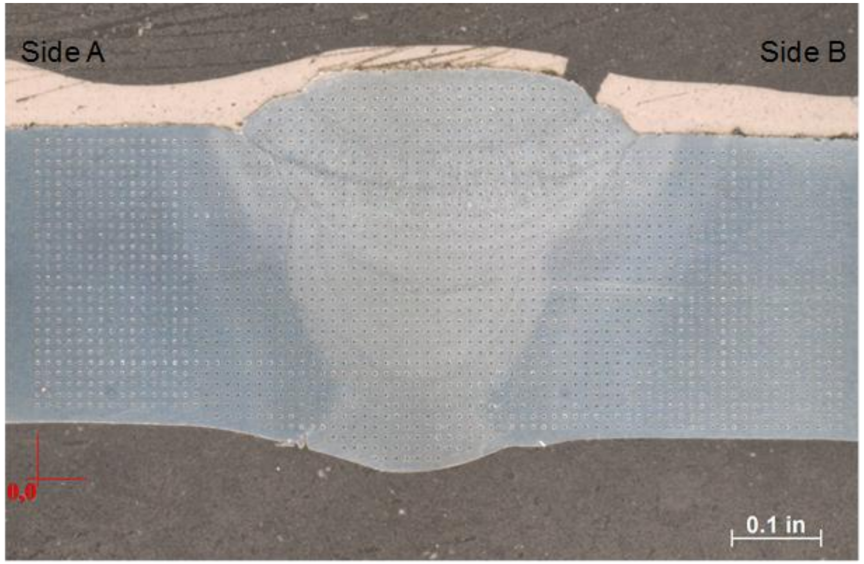
Examples of Girth Weld Flaws in Vintage Pipelines

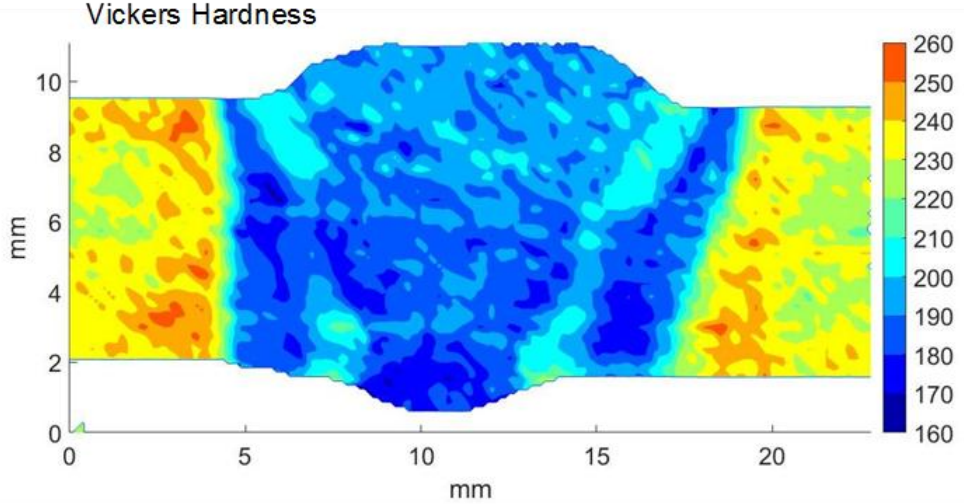




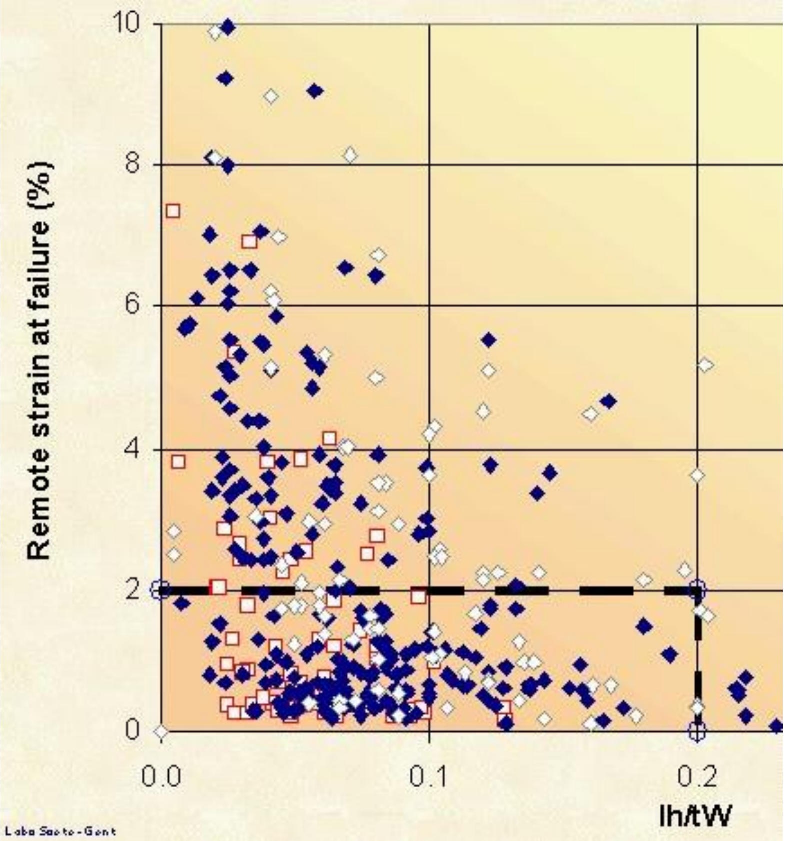
Incident of a New Pipeline

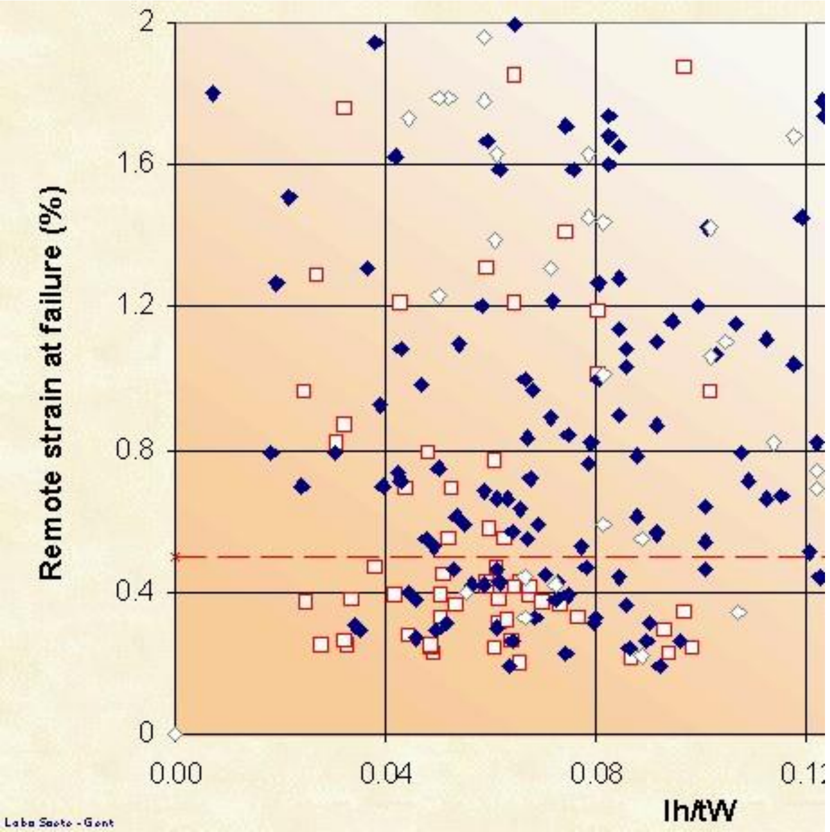
- Key Incident data
  - Pipeline: X70, 24” OD HFI
  - Occurred in the winter of 2017/2018
  - Length of time after construction: 3.5 years

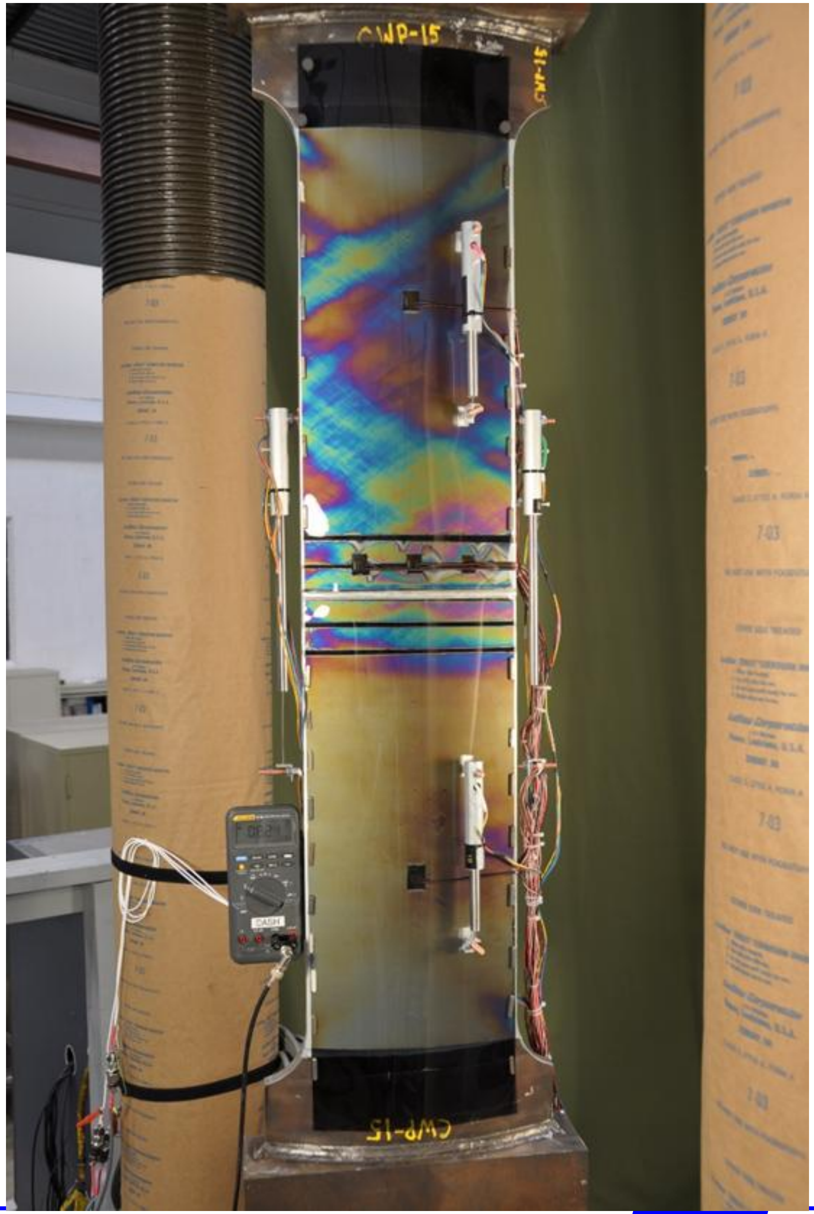




Possible TSC of Girth Welds







Girth Welds Can Be Made Very Resilient

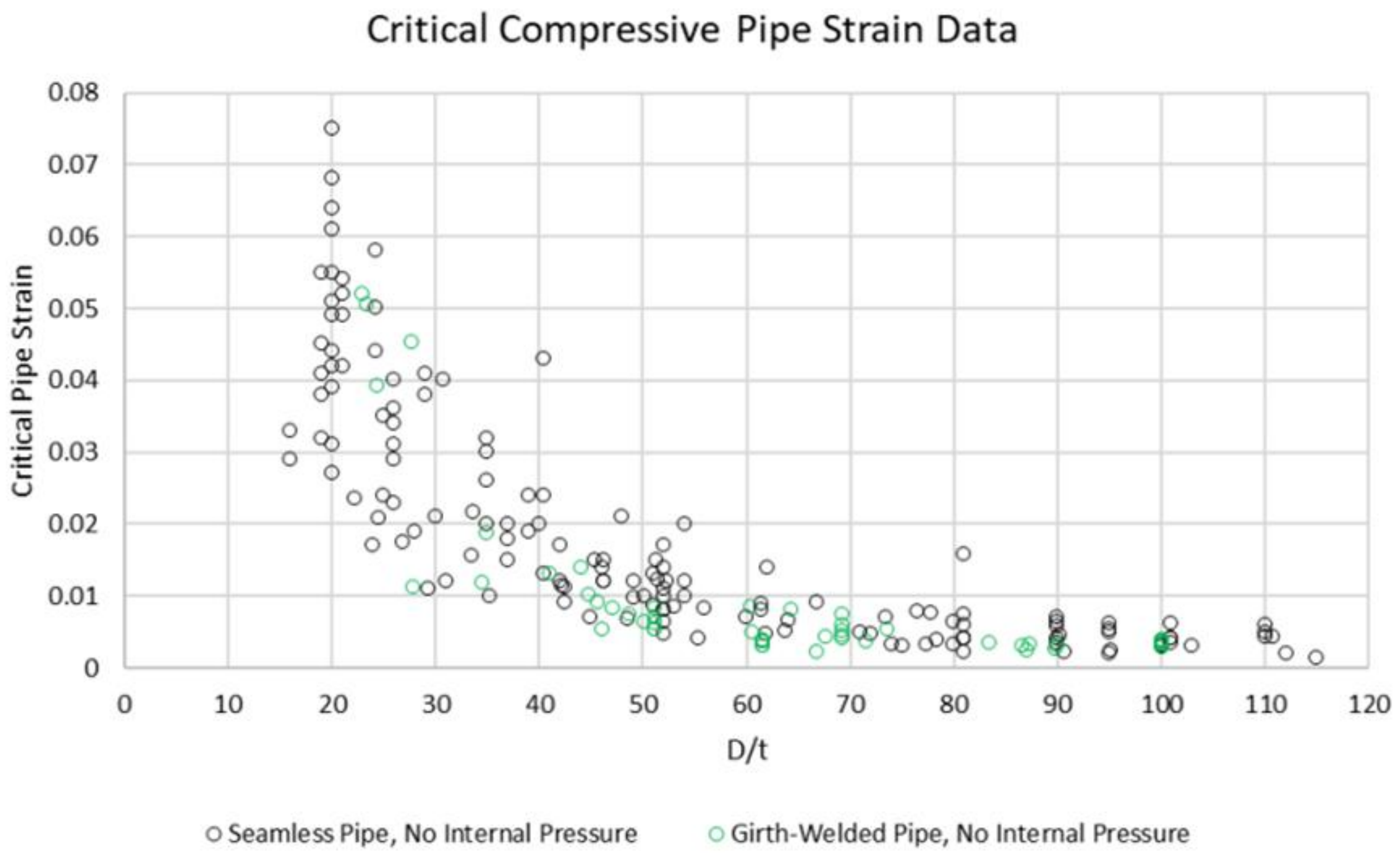
- Newly constructed pipeline
- Code-compliant
- Had a 17-ft landslide
- Girth welds survived
- Wrinkle was formed

Part 2.3.4

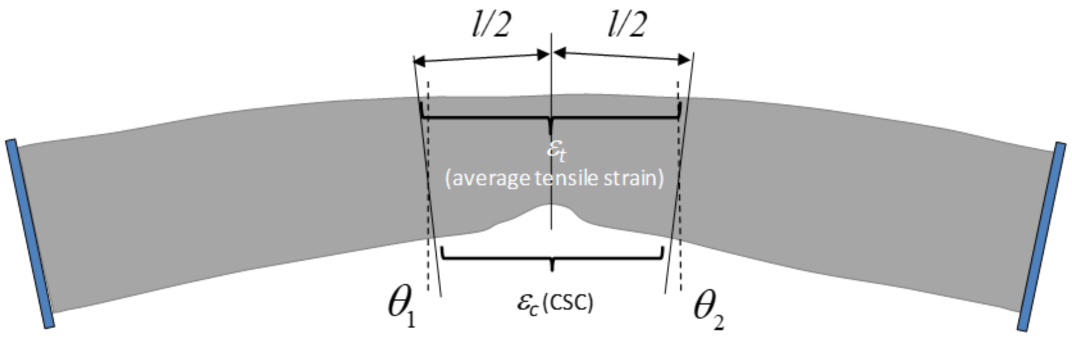
Compressive Strain Capacity

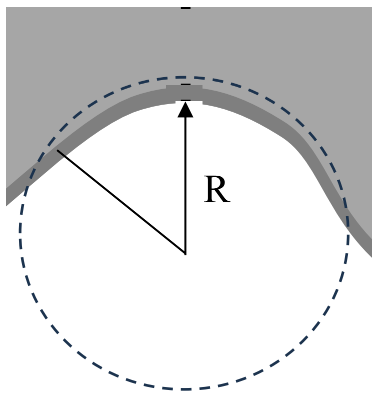
Compressive Strain Capacity (CSC)

- Many published models are available
  - CSA
  - API
  - DNV
  - University of Alberta
  - CRES
- CSC is given at a strain corresponding to maximum bending moment or maximum load.
- These models/equations are overly conservative for buried pipelines.



CSC – Alternative View





- For displacement-controlled loading, setting limits using alternative criteria:
  - Wrinkle height
  - Magnitude of local strain
- The outcome would be more useful for making practical decisions.

Part 2.3.5

Strain-Based FFS Assessment

Strain-Based FFS Assessment

- Safe condition

$$\varepsilon_d \text{ (strain demand)} \leq \varepsilon_d^L \text{ (strain demand limit)}$$

$$\varepsilon_d^L = \varepsilon_c \text{ (strain capacity)} / f \text{ (safety factor)}$$

- Strain demand can be time-dependent or time-independent
  - Time-dependent such as a slow creep of soil movement over time
  - Time-independent such as a weather event resulting in a subsidence
- Strain capacity can be time-dependent or time-independent
  - Time-dependent if C-SCC, circumferential corrosion, or fatigue crack growth of a girth weld is involved

Part 3.1

Integrity-Centric Geohazards Management Program

Managing Geohazards vs. Other Threats

- Most threats being managed by a pipeline company, e.g., corrosion, mechanical damage, cracking
  - Demand: Internal pressure or hoop stress
    - History and magnitude are generally known.
    - It can be “controlled” in the future.
  - Capacity, e.g., level of pressure a pipeline may sustain
    - Capacity relative to some threats, such as corrosion, is well understood.
    - Capacity relative to some other threats, such as SCC, can have large variations.
    - May deteriorate over time.
  - The focus is on managing capacity.
    - For example, capacity is P_{burst} where a safety condition is P_{burst} > MOP x FOS

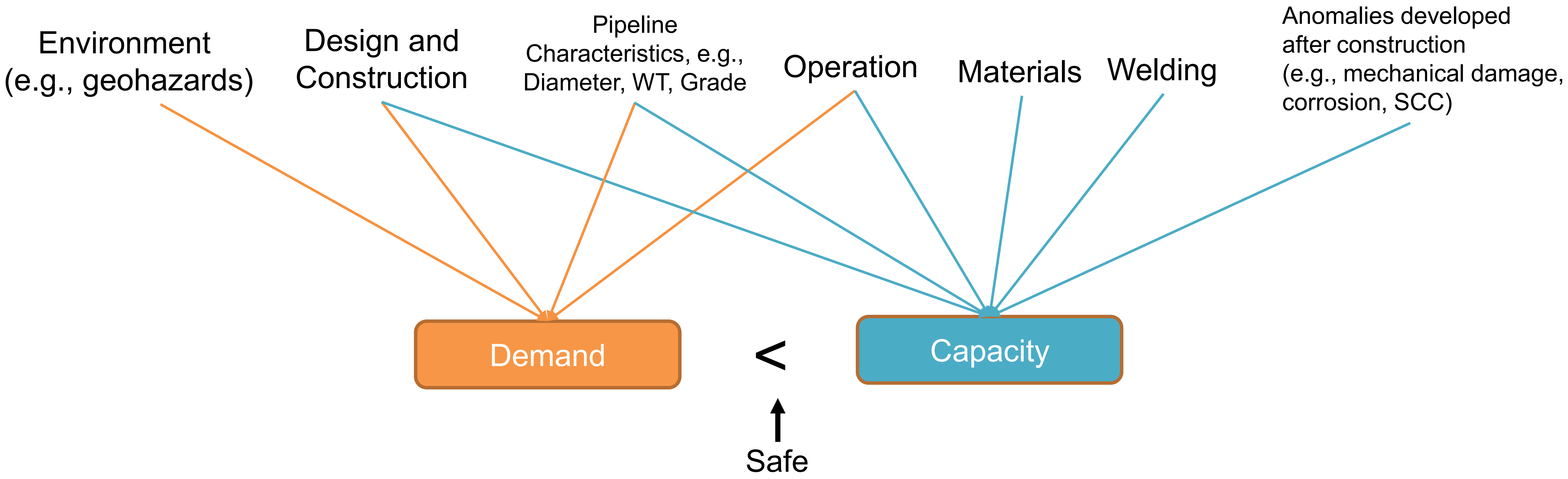
Managing Geohazards vs. Other Threats

- Geohazards
  - Demand: axial/longitudinal stress/strain
    - History is generally unknown.
    - Precision on the magnitude varies.
    - Ability to “control” the magnitude varies.
  - Capacity, ability to tolerate longitudinal stress/strain
    - Often poorly understood
    - Can have large variations from pipeline to pipeline and even with the same pipeline
    - May deteriorate over time (i.e., circumferential corrosion, C-SCC)
  - <u>Both demand and capacity have to be managed.</u>

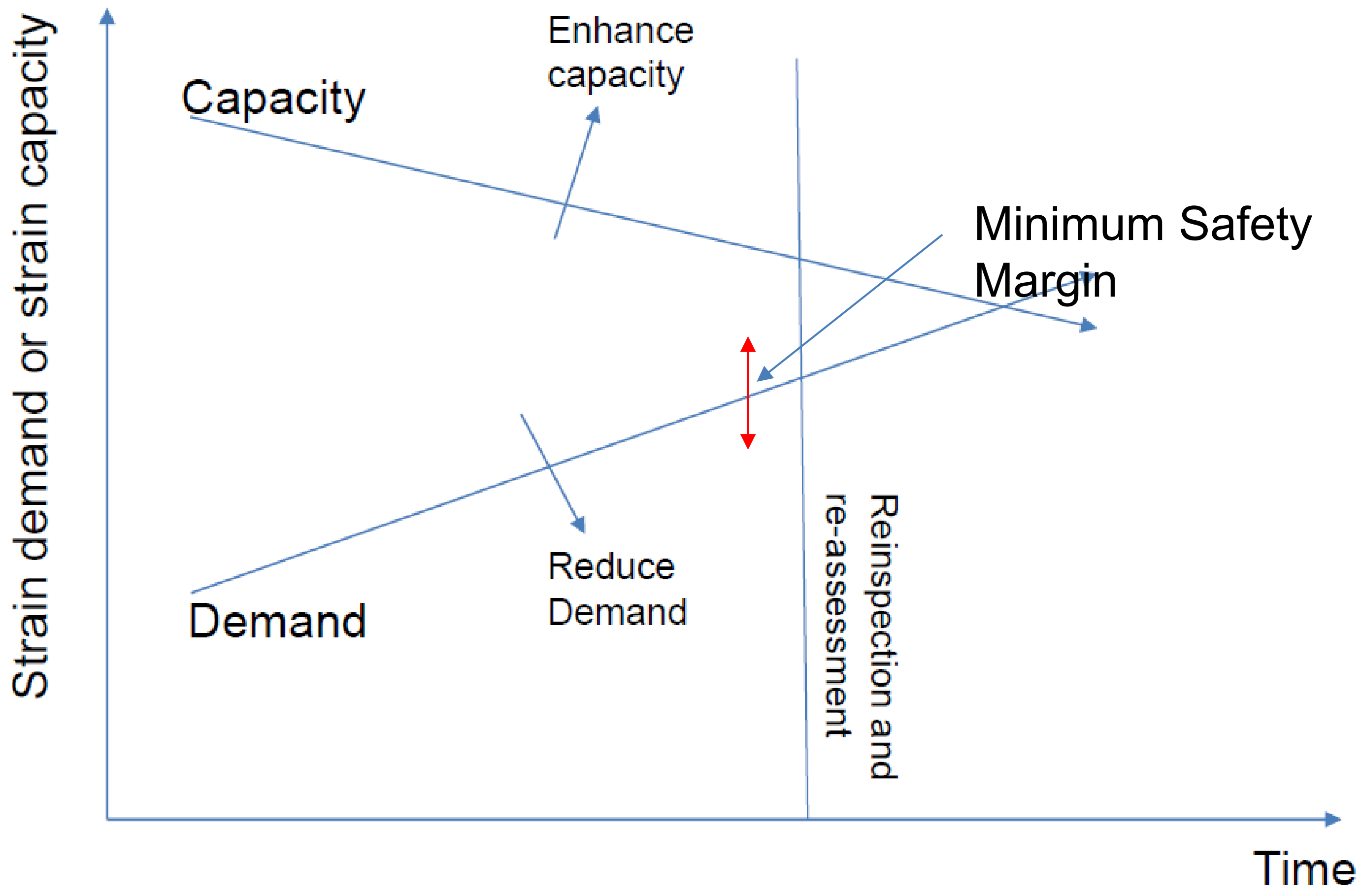
Integrity-Centric Geohazards Management

- Pipeline integrity is at the core of the process.
- Use integrity assessment to drive decisions about mitigation decisions
  - Necessary?
  - When?
  - How?
    - Hazards
    - Pipe
- Often involve multiple steps, e.g., a two-step process
  - Screening
  - Site-specific analysis

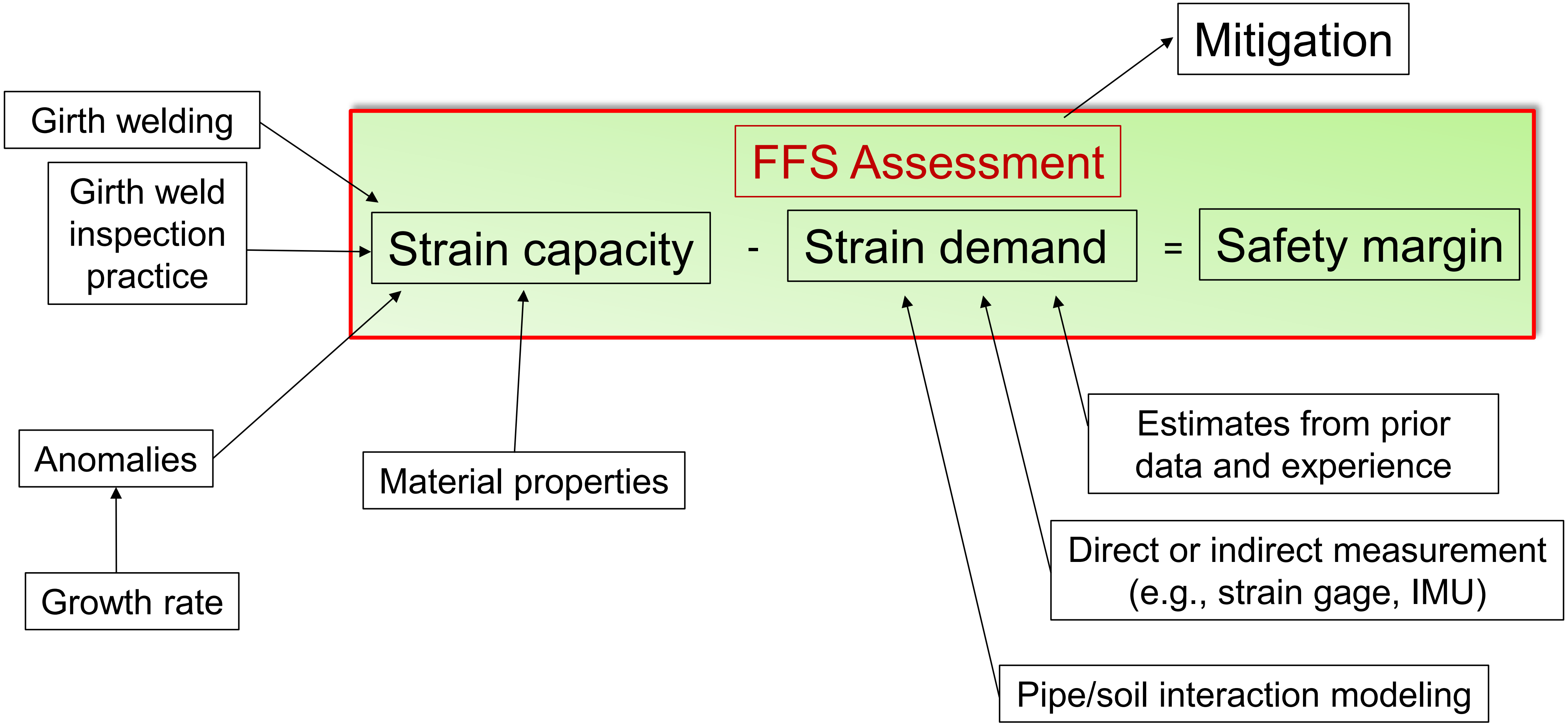
Holistic View of Pipeline Integrity



Integrity Management Using Safety Margin as a Critical Indicator

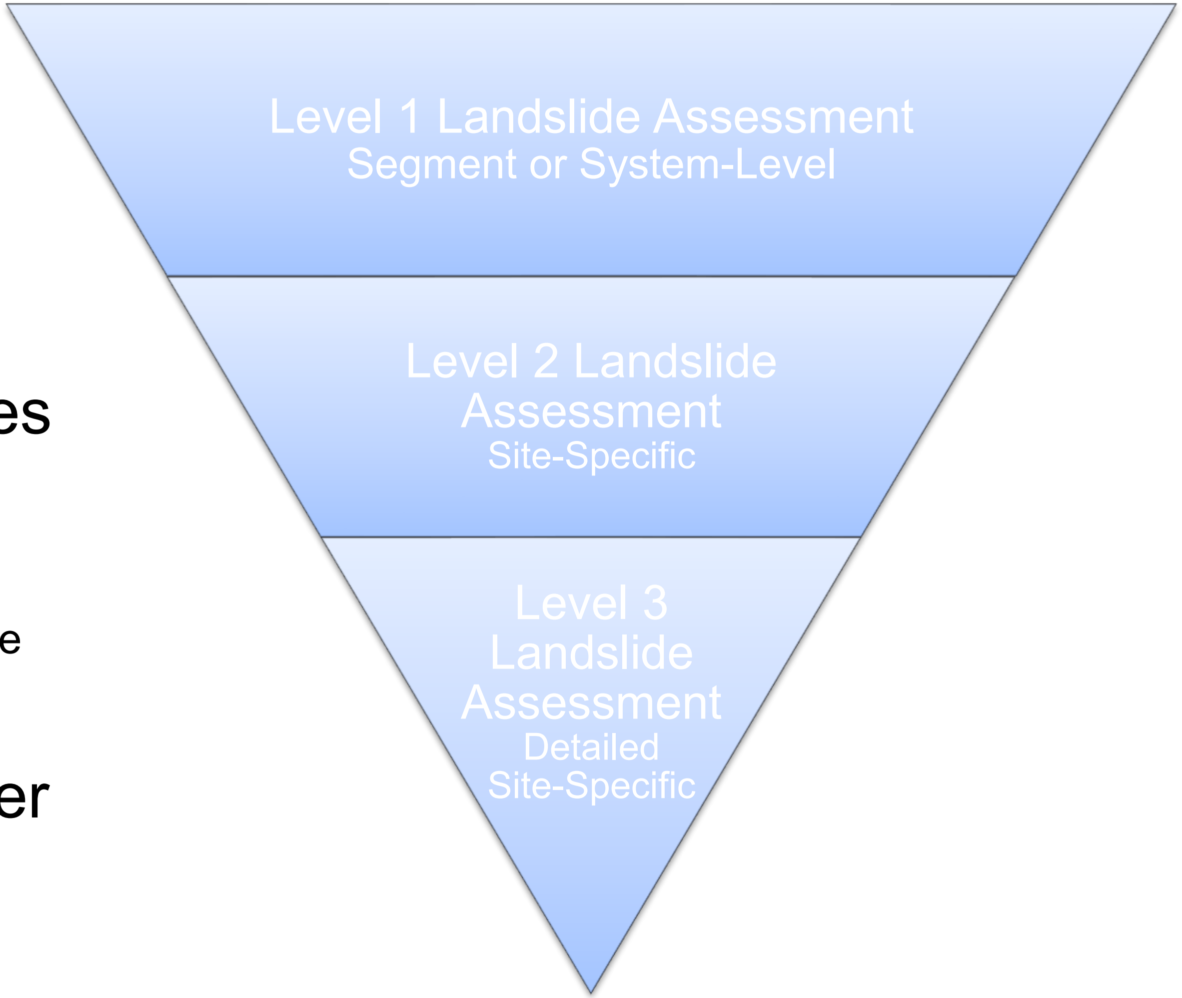


Integrity Assessment Based on FFS Principles



Integration of Hazards and Integrity Assessments in RP 1187

- ❑ Integrity assessment is nested inside a three-level structure primarily built on hazards assessment.
- ❑ Integrity assessment can start at any level within the three-level structure
- ❑ Some companies bring in integrity assessment at Level 2 or Level 3 Landslides Assessment, i.e., not at Level 1
  - ❖ Potential downside in rare cases:
    - ► Understating risk for pipelines with very low strain tolerance
- ❑ Other companies may start with ILI IMU (strain demand) with confirmation from other hazards characterization methods



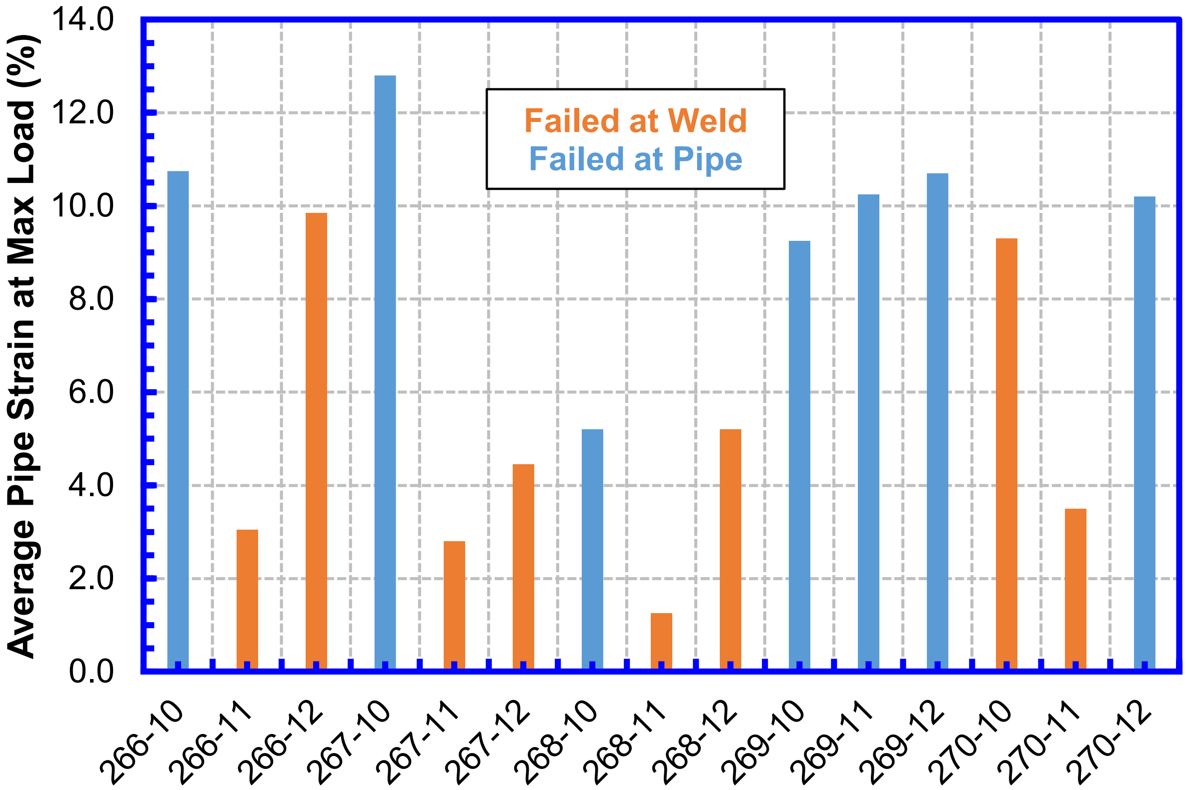
Integration of Hazards and Integrity Assessments in RP 1187

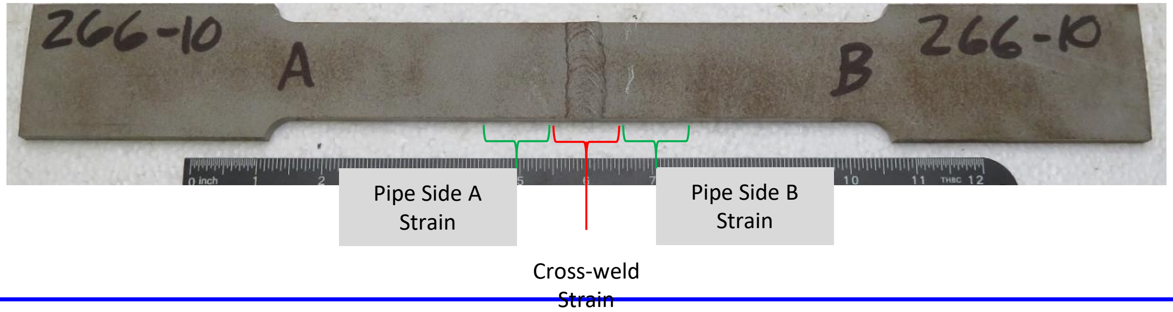
- Integrity-focused parts
  - Annex C Fitness-for-Service Assessment in Landslide Management
  - Annex I Interacting Threats in Landslide Integrity Management
- Parts with major elements in integrity assessment
  - Annex D Landslide Assessment Examples
  - Annex G Landslide Threat Management Measures
    - Enhancing strain capacity

Estimation/Determination of Strain Demand

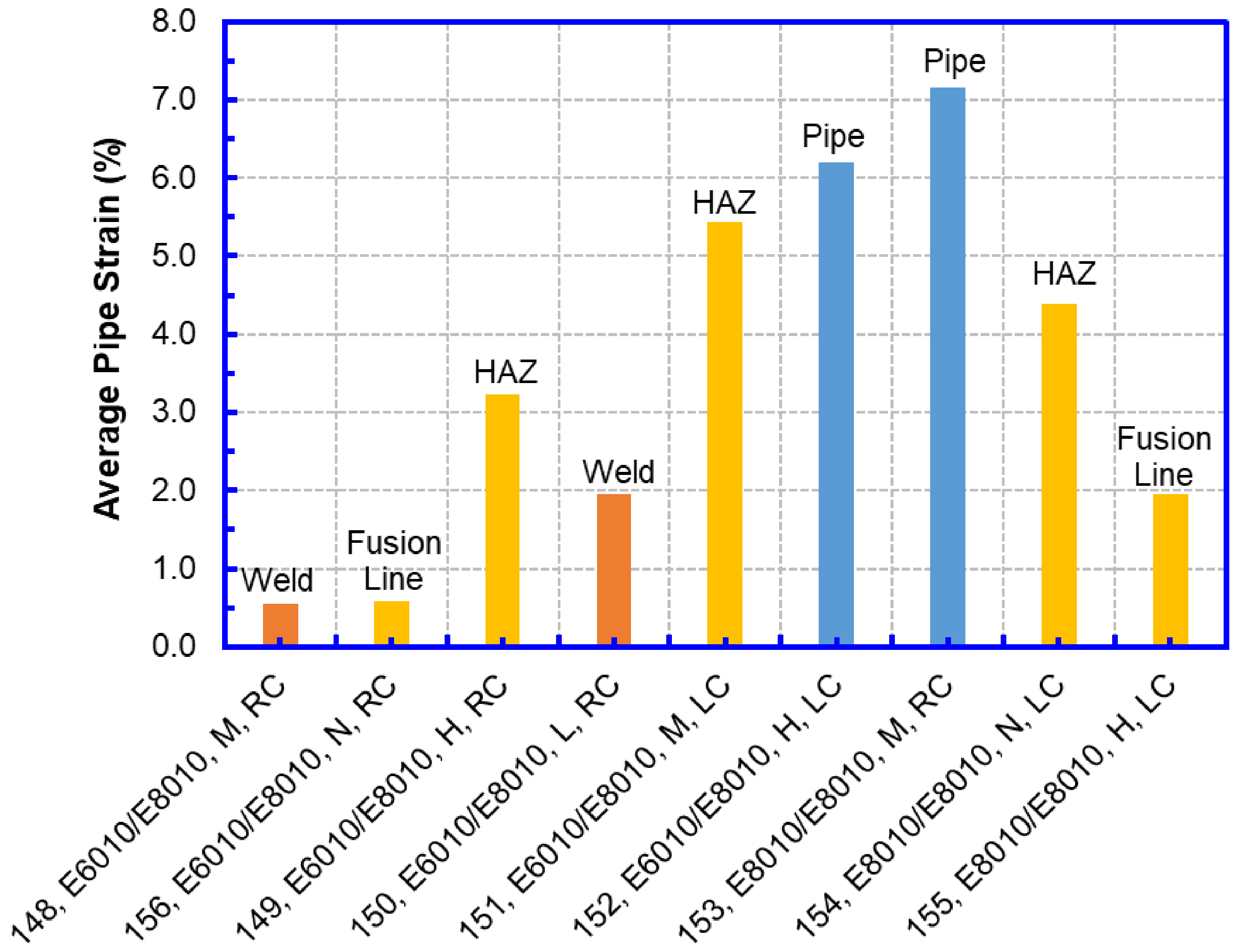
- Quick strain demand estimation based on deformation profile
- Screening and analysis of IMU data
  - Blind spots / challenges
    - Bends limit IMU ability to determine strains (need to interpolate based of strains adjacent to bends)
    - Weld “bumps” (hi-lo, and minor miter at girth weld can result in false strain calculation)
    - Correlation with geohazards at low level of bending strain
  - Comparison of previous IMU data
  - Overlay of Geometry and IMU data to rule out false positives
- Analysis of strain gage data
  - Resolution of bending plane
  - Separation of bending vs. uniform tensile/compression components
  - Temperature compensation
- Pipe-soil interaction modeling

Varying Tensile Strain Tolerance in Vintage Girth Welds





Varying Tensile Strain Tolerance in Modern Girth Welds



Root and hot passes

- E6010 or
- E8010

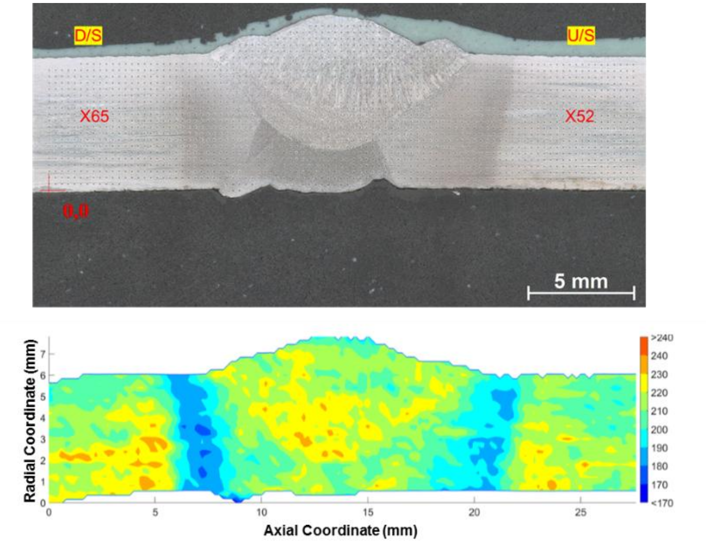
Heat input

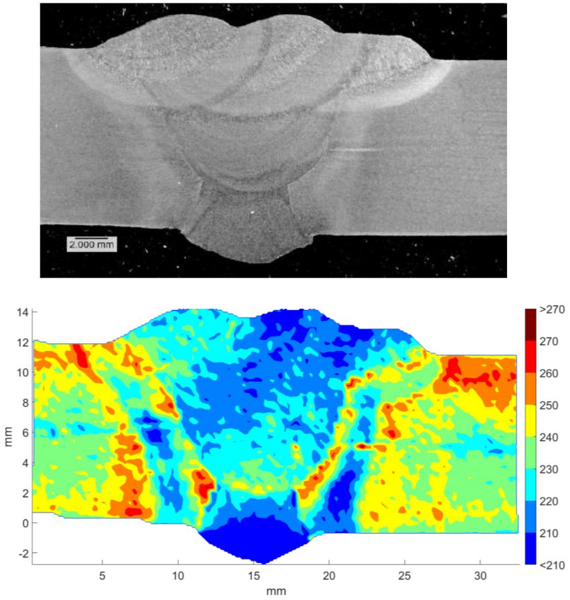
- Median (M)/Nominal (N)
- Low (L)
- High (H)

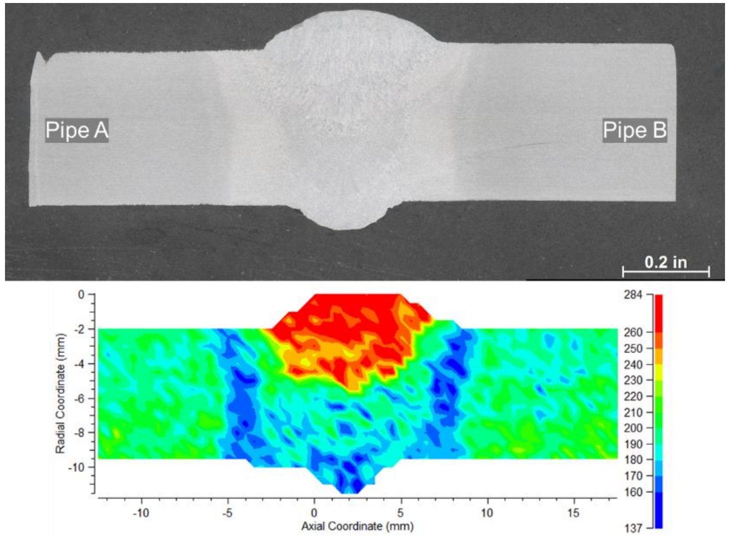
Cap reinforcement

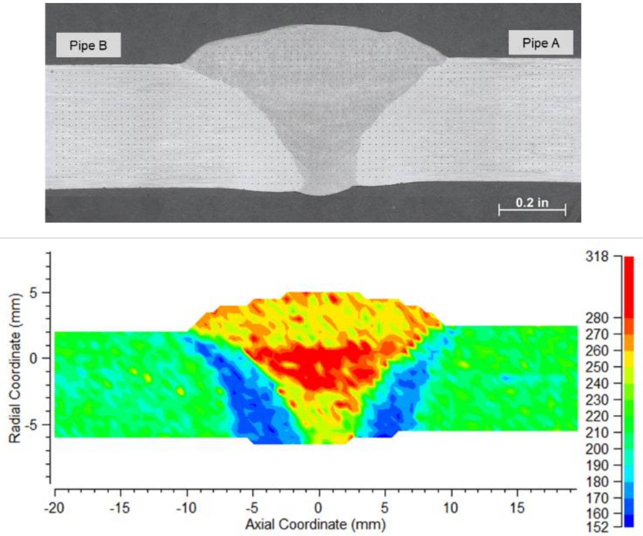
- Regular cap (RC)
- Large cap (LC)

Local Strength Distribution in the Weld Area in Modern Girth Welds



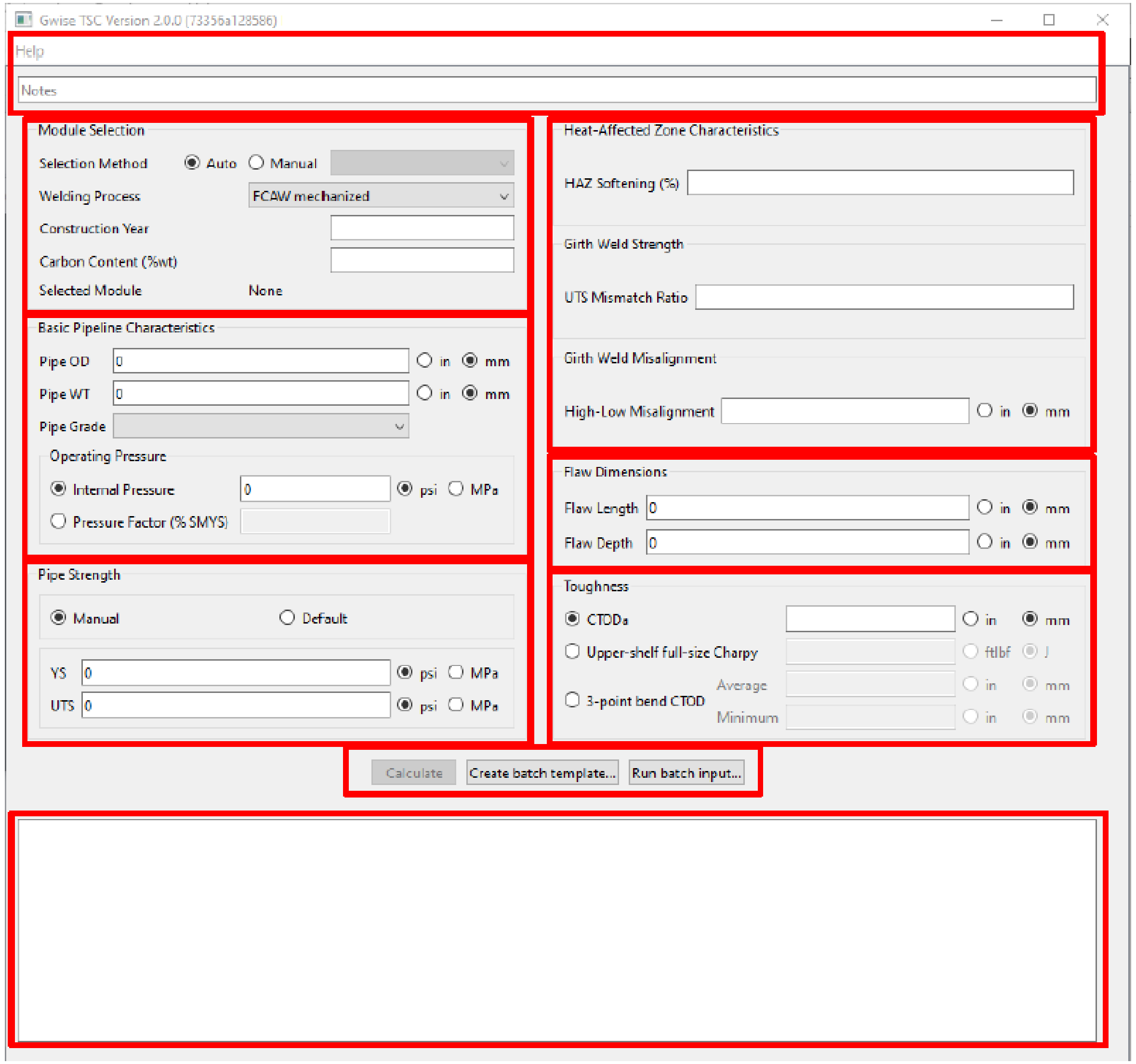






Key Enabler – TSC Tool and Associated Data Collection

- Gwise® -TSC
  - Gwise® is a registered trademark of CRES based on PRCI-CRES Models
  - Gwise®-TSC is a toll that provides relations between TSC and major factors affecting TSC.
  - Applicable range
    - Vintage (1930's) to present day
    - Grade B to X70/X80
    - OD: 8"-48"
- Data collection
  - Material properties
    - Pipe
    - Welds
  - Girth weld dimensional features
  - Girth weld anomalies



Part 3.2

Data Collection and Continuous Improvement

Details are supported in Annex I.

Interacting Threats

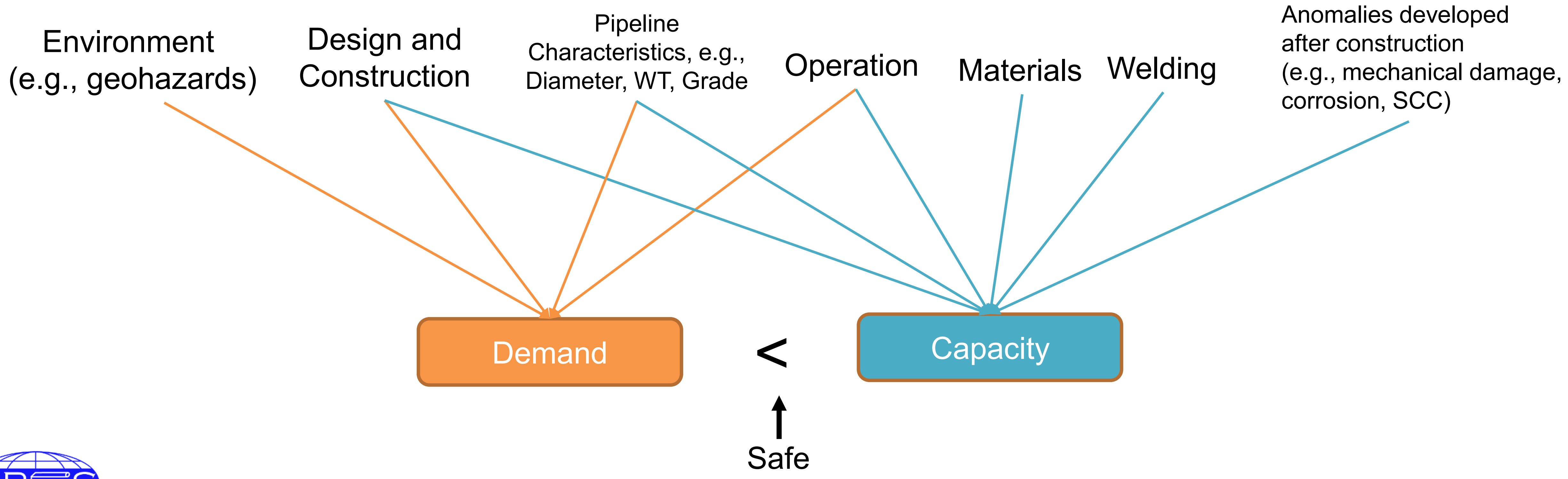
- High axial/longitudinal stress with
  - Corrosion
  - Mechanical damage
  - Cracks
- Both or more threats together
- Examples
  - Corrosion in geohazards area
  - Cracks in corrosion
  - Cracks in mechanical damage
  - Cracks in corrosion in geohazards area
  - Cracks in mechanical damage in geohazards area

Interacting Threats – Industry Practice

- For the most part, no consistent approaches
- Going forward
  - Responsibilities within an organization
  - Consistent and verified technical approach

Managing Interacting Threats – Data Integration

- Type of data
  - Hazards
  - Over pipeline characteristics
  - Pipeline anomalies
- Tools
  - Records
  - ILI
  - History, e.g., monitoring



Part 4.1

Practical Examples

Example 1 – More Hazards Focused

- Identify sites of landslides
- Assess the severity of the hazards
- Monitoring
  - LiDAR
  - Ground monitoring
  - Strain gage
- IMU used as a confirmation tool, not a quantitative tool
- No differentiated strain capacity

Example 2 – More Integrity Focused

- Strain demand
  - IMU
  - LiDAR and other hazards characterization
- Strain capacity
  - Characterize mechanical properties and girth weld flaw workmanship
  - Determine tensile strain capacity (TSC)
- Initial assessment / screening
  - Compare strain demand with TSC, incorporating safety factors
- Further assessment
  - On-site assessment of hazards
  - Refinement of strain capacity

Example 3 – More Integrity Focused

- After an incident
- Extensive work was done to establish TSC for different pipe and GW configurations
- Action thresholds were established.
- SGs are installed and monitored
- Actions would be taken when the strains from SGs approach the established threshold.

Example 4 – A Site-Specific Example

- A pipeline segment was displaced by a landslide.
  - Should normal operation be continued?
- Level 1 quick turn-around FFS assessment was completed
  - No immediate integrity concerns were identified.
  - The line remained in service with full pressure.
  - Site mitigation was planned in dry months.
- Leve 2 FFS assessment was completed while mitigation options were explored.
  - The margin of safety was good.

Example 4 – A Site-Specific Example

- Site work
  - No stress relief
  - Drains were installed.
  - Strain gages were installed in critical locations identified by the strain demand analysis
- Future integrity management
  - Strain threshold for future intervention/action
  - Monitoring/reporting processes

Example 5 – Another Site-Specific Example

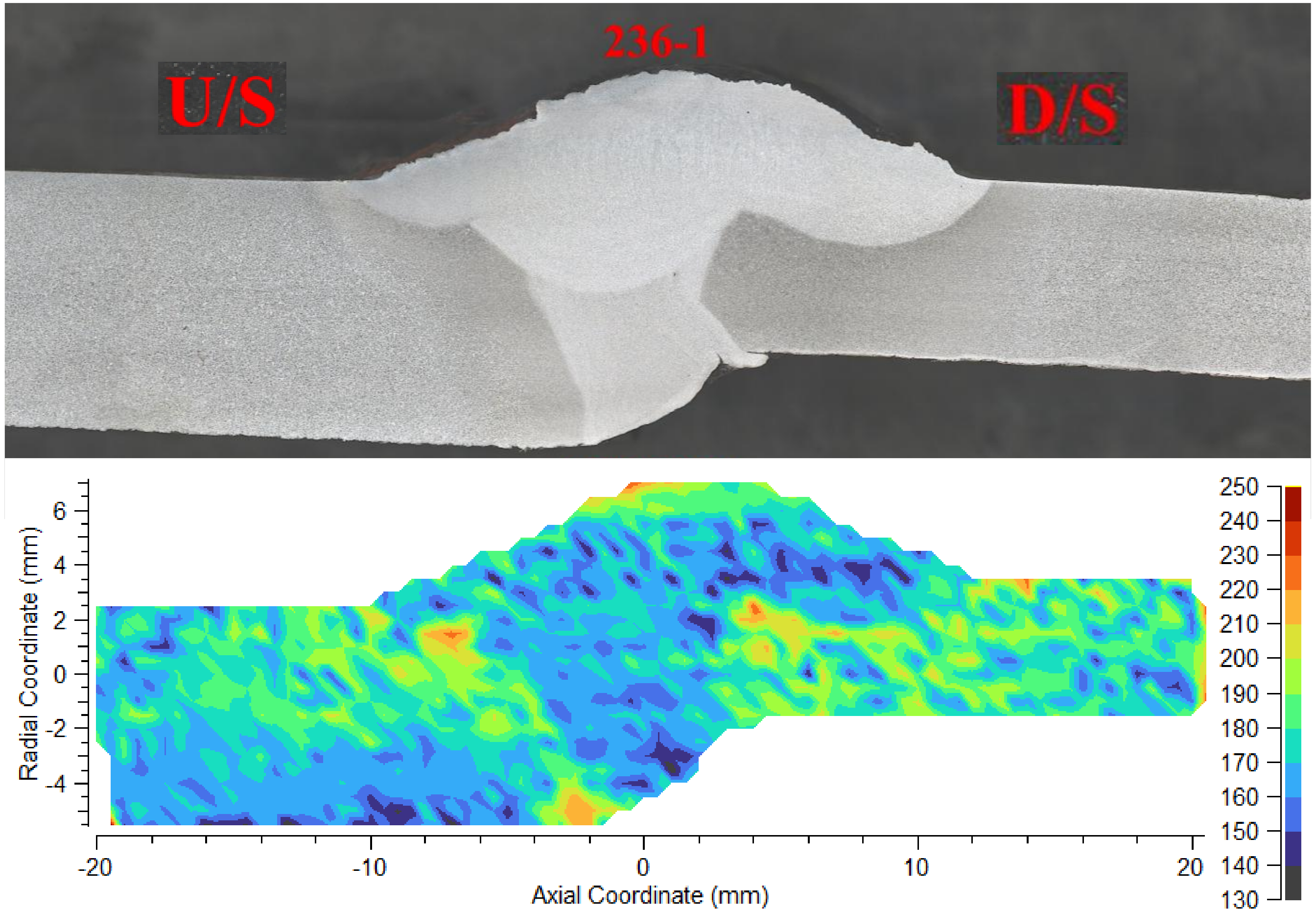
- Recommendations – Site 1
  - Site stabilization
  - No stress relief
  - Continued monitoring
- Recommendations – Site 2
  - Stress relief (low capacity, low margin)
  - Site stabilization
  - Monitoring

Landslide Site No.	1	2
Total Span (ft)	160	130
Max. Displacement (ft)	3.5	2.0
Strain Demand (%)	0.35-0.60	0.22-0.30
Strain Capacity (%)	0.90-1.45	0.55-0.65
Capacity - Demand (%)	0.55-0.85	0.15-0.35
Demand/Capacity	0.40-0.43	0.35-0.70
Allowable Additional Displacement (ft)	4.0	1.0

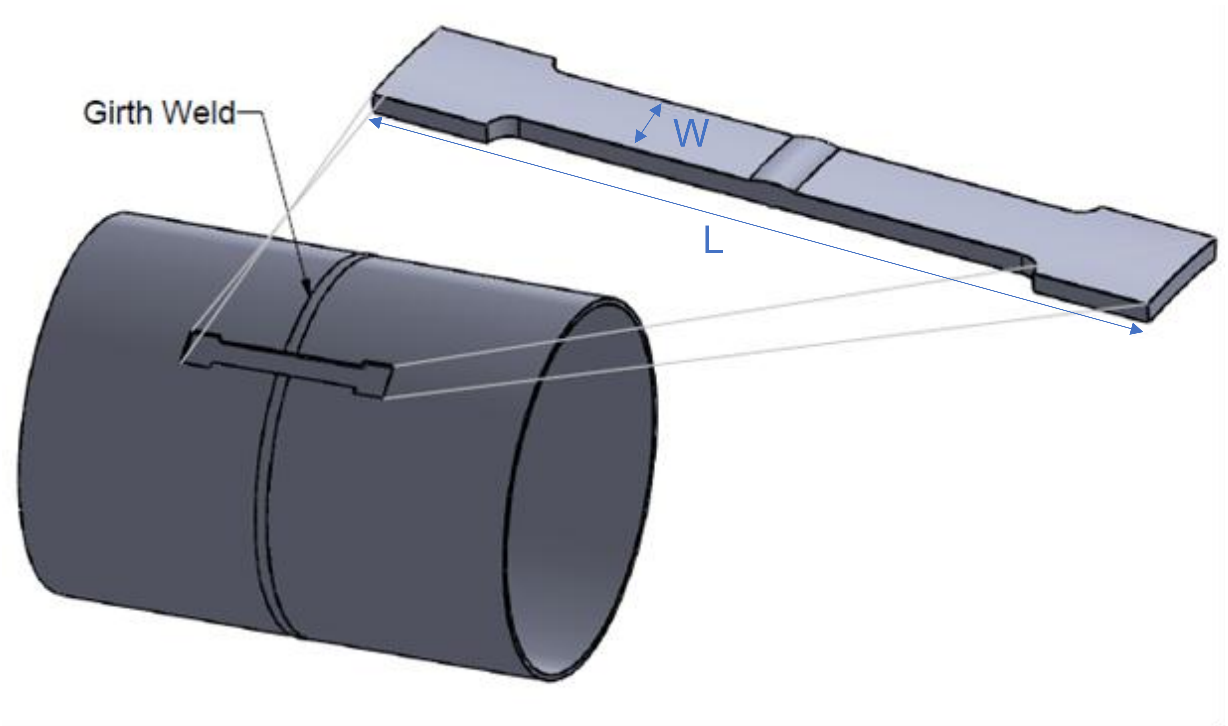
Example 6

Understanding the strain tolerance of vintage pipelines

Girth Weld Microhardness



Instrumented Cross-Weld Tensile Testing

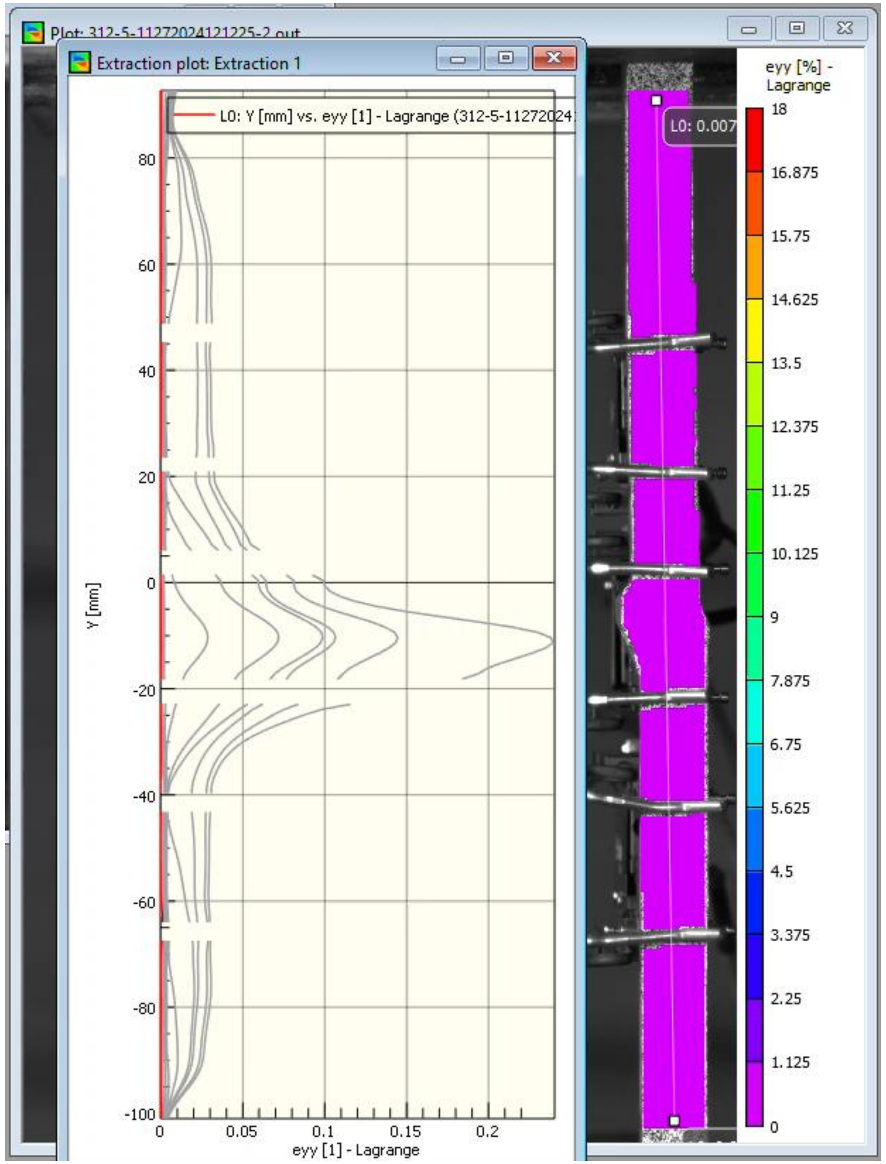


Extensometer for Pipe Side A

Extensometer for cross-weld region

Extensometer for Pipe Side B

ICWT Test as Captured by DIC



Example 7 – Capital New Construction Projects

- Reduction in strain demand
  - Route selection and planning
  - Special construction practice
    - HDD
    - Drainage
    - Trench profile
    - Backfill material
    - Geotextile
- Enhancement in strain capacity
  - Specifying and procuring the “right” pipes
  - Making robust welds
- Monitoring and intervention
  - Install monitoring devices
  - Establish intervention threshold

Part 4.2

Building effective geohazards management program – high-level strategy

Key Enablers for Effective Geohazards Management

- Have a strategy and plan
- Collect data whenever possible
- Understand the differences between geohazards management and managing other threats
  - Demand and capacity can both be time dependent
  - Internal pressure has small impact on the likelihood of failure in most cases
    - Safety margin is the difference between capacity and demand measured in axial direction
- Use tools wisely
  - Understand blind spots

Enabling Integrity-Focused Geohazards Management

- Prepare data for FFS assessment
  - Vintage pipelines
    - Test pipes and girth welds (opportunistic testing)
    - Understand flaw characteristics of girth welds
  - Modern pipelines
    - Organize records
    - Perform targeted tests as needed
- Have a pre-defined framework
  - Overall geohazards management process (e.g., RP 1187)
  - Process to collect samples and conduct tests
  - Organize data in useable forms

Should One Start with Demand or Capacity in GM Process?

- In an early stage of a GM (geohazards management) program, one can start with demand (i.e., hazards), then bring in capacity
  - Except if the capacity is very low due to
    - Possible existence of large weld flaws,
    - Low toughness, and/or
    - High levels of weld strength undermatching or HAZ softening.
- Once a GM program is under way, it's advisable to work on both demand and capacity at the same time.
  - Planning and data generation and management in advance is often necessary.

References

- McKenzie-Johnson, A., Theriault, B., Wang, Y.-Y., Fleck, P., Ebrahimi, A., Liu, B., and West, D., April 2023, “Recommended Practice for Pipeline Integrity Management of Landslide Hazards,” https://ingaa.org/wp-content/uploads/2024/12/RP-for-Pipeline-IM-of-Landslide-Hazards-2023-002.pdf.
- Wang, Y.-Y., Fleck, P., McKenzie-Johnson, A., Theriault, and West, D., “Framework for Geohazard Management,” March 31, 2023, https://ingaa.org/imci-2-0-2023-framework-for-geohazard-management/
- Wang, Y.-Y., et al., “Management of Ground Movement Hazards for Pipelines,” CRES Project No. CRES-2012-M03-01, final report, February 28, 2017, https://ingaa.org/management-of-ground-movement-hazards-for-pipelines/

Thank You!

Q&A