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PRCI Research Exchange

Guidance on Welding Procedure Qualifications to Prevent Low Strain Failures of Girth Welds

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Overview

- Problem statement
- Holistic view of girth weld integrity
- Current requirements in girth weld procedure qualifications
- Linkage
  - Actual strength of pipe
  - Impact of welding heat input
  - Tensile strain capacity of undermatching girth welds
  - Strain demand from field service conditions
- Qualification requirements
  - Requirements rooted in fundamentals
  - Practical requirements in consideration of current practice
- Concluding remarks

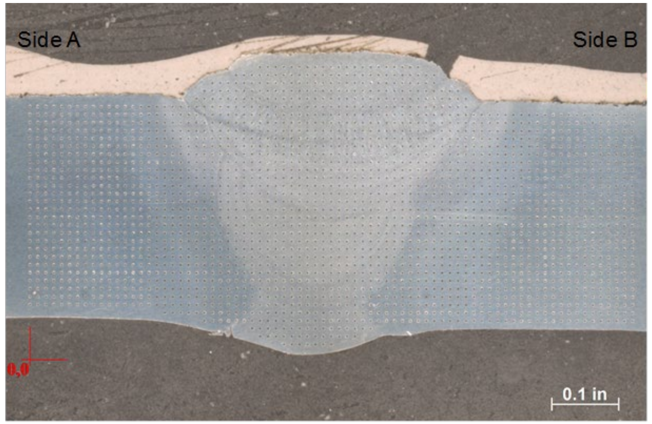
Problem Statement – Grith Weld Failures at Low Strain

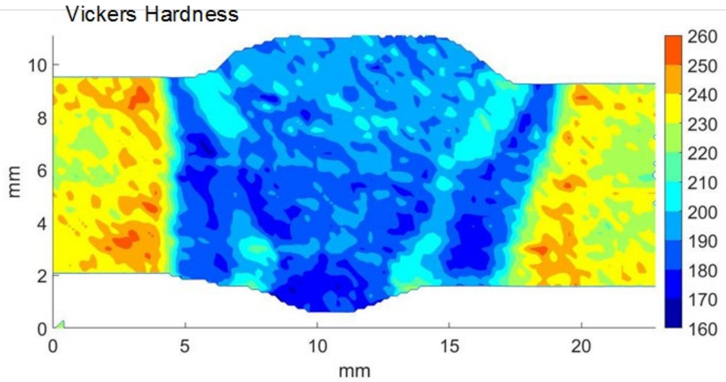
- **Recent systematic investigation started ~2015**
- **Incidents**
  - occurred in-service and during hydrostatic testing
  - 30+ incidents.
    - US
    - Asia
    - South America
  - Grade: X52 to X80
  - Manual or semi-automatic welds
- **Some incidents before 2015 may have similar contributing factors.**

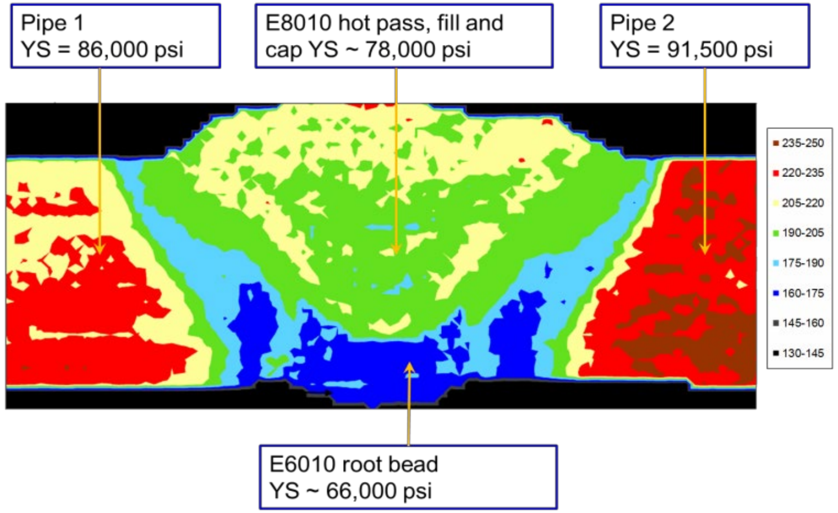
Incident No.	OD (inch)	Grade	Nature of Incident	Approximate Elapsed Time for Start of Service
1	20"	X70 PSL2	In-Service Rupture	1 Year
2	30"+	X80/X70	In-Service Rupture	6 years
3	12.75"	X52	In-Service Leak	14 years
4	30"	X70M	Hydrostatic Leak	N/A
5	30"	X70	Hydrostatic Leak	N/A
6	42"	X70 PSL2	In-Service 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

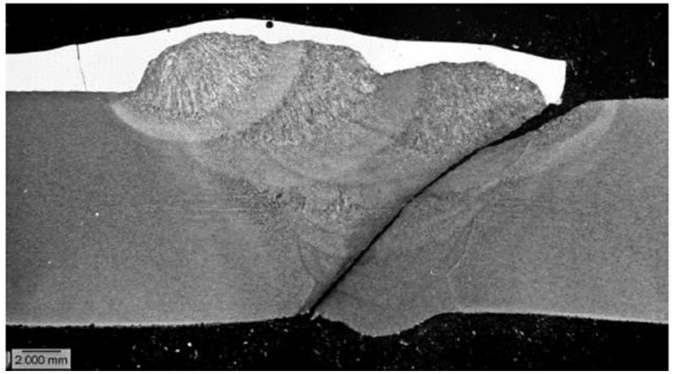
Major Contributing Factors to Observed Failures

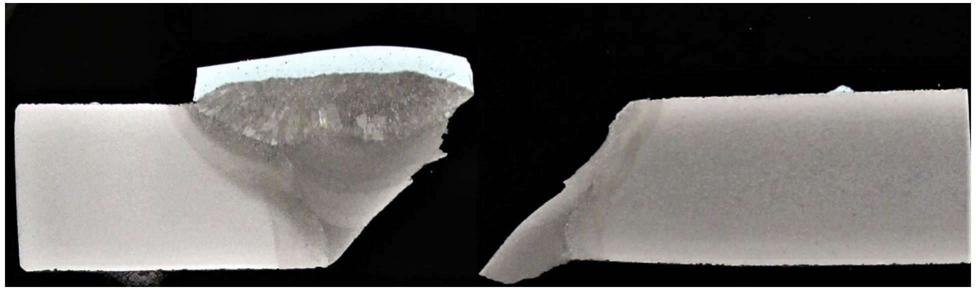
- **Weld strength undermatching**
- **HAZ softening**
- **Elevated stress**



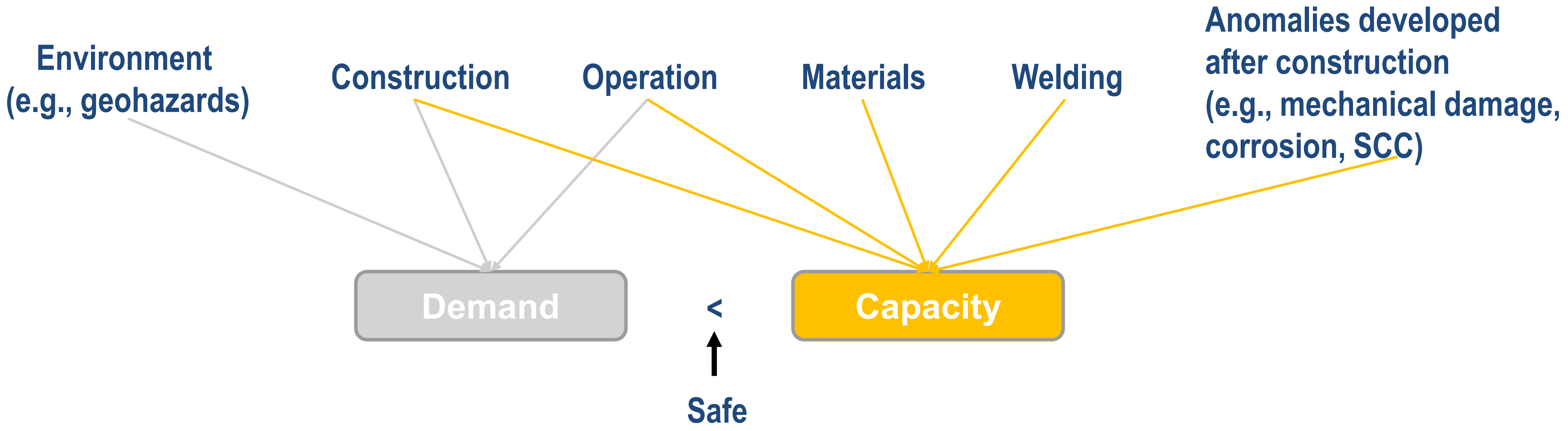








Holistic View of Girth Weld Integrity



Current Approach in Welding Procedure Qualification

- **Main body - workmanship**
  - High priority – having “sound welds”
    - Prevention, detection, and repair of flaws
  - Nominal requirements
    - Weld strength, ≥ specified minimum strength of the pipe
    - Ductility
  - Not considered
    - Connection between qualification requirements and field service condition (expected stress level) in rigorous engineering sense
      - However, workmanship historically has worked well for the industry.
- **ECA**
  - Add toughness to the requirement of main body (e.g., CTOD)
  - Flaw acceptance criteria are related to field service conditions
    - Considerations for field service conditions may not be adequate.
    - Conservatism in other areas makes up the deficiency; ECA welds are of good quality.

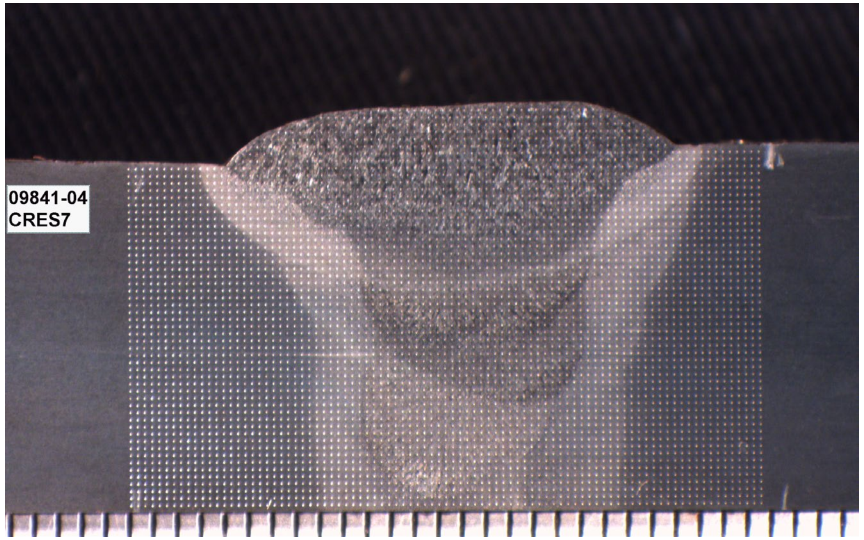
Contrasting Qualification Requirements with Factors Affecting Weld Performance

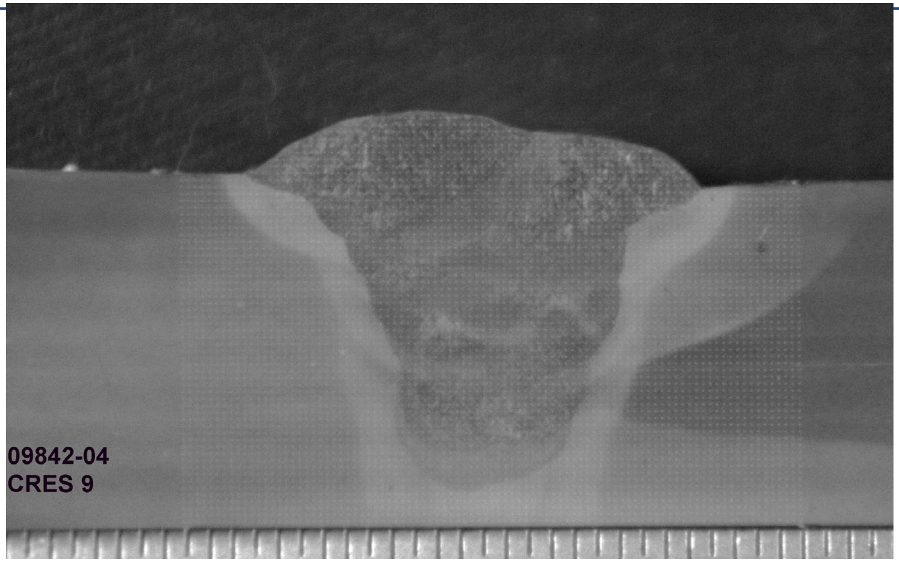
Factors Affecting Girth Weld Performance		Factors Addressed in API 1104
Pipe wall thickness		Mostly Yes
Pipe strain hardening capacity		No
Weld strength mismatch	YS mismatch	No
	UTS mismatch	No
HAZ strength (Softening)		No
Weld profile	Cap reinforcement	Mostly No
	Misalignment	No
	Bevel geometry	Yes
Weld flaw	Flaw type	Yes
	Flaw dimensions	Yes
Toughness		No
Applied stress/strain		No

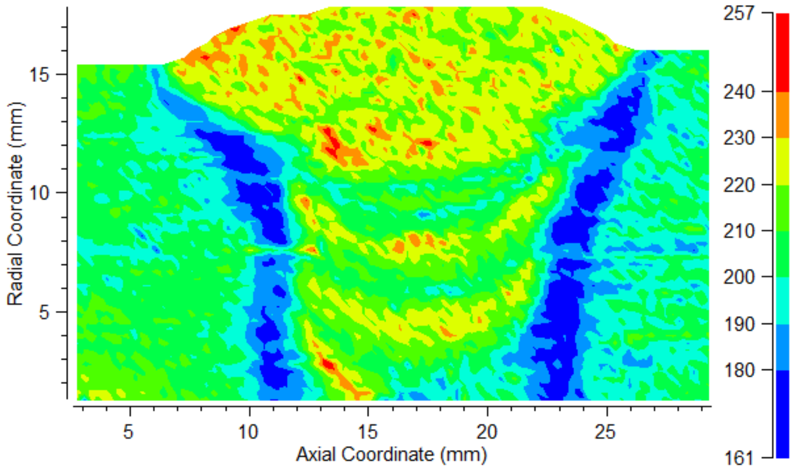
Contribution of Current Requirements to Low Strain Tolerance

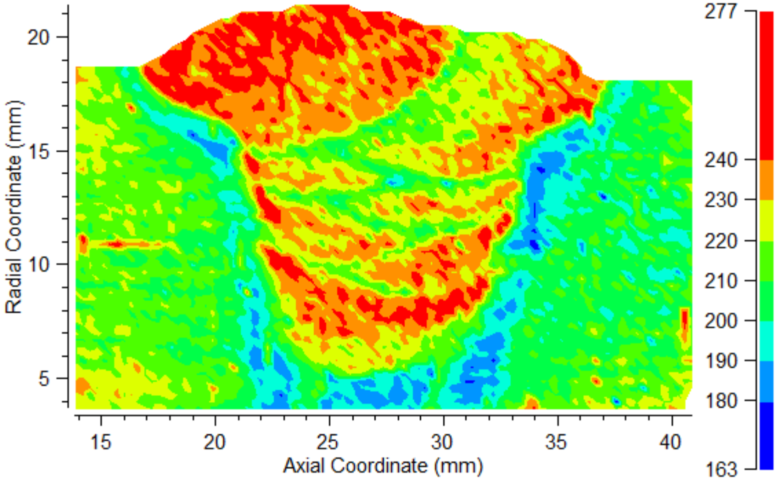
- **Weak link between actual pipe strength and welding procedures requirements**
  - Permit girth weld strength undermatching
- **Heat input may have a wide range, affecting**
  - Weld metal strength
  - Level and extent of HAZ softening

Effects of Heat Input on Weld Metal and HAZ Strength









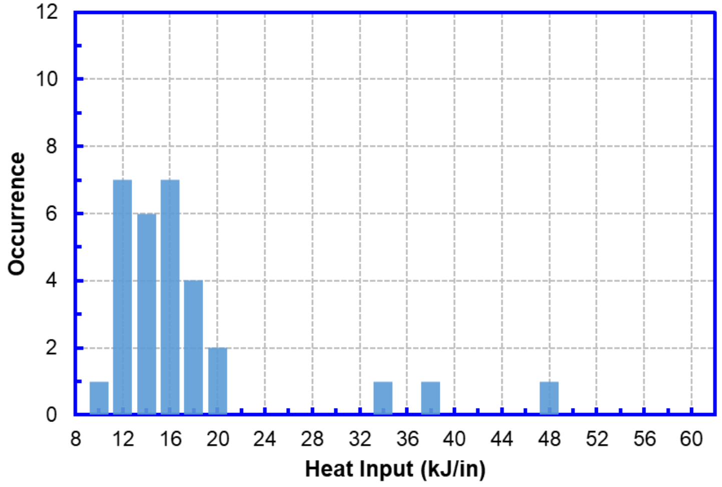
Same pipe and consumables (E6010 root, E81T8 hot, fill, and cap)

Ref: Jia, D., Wang, J., and Wang, Y.-Y., “Evaluation of Semi-Automatic FCAW-S Welding Processes and Implications for Pipe-line Girth Weld Integrity,” PRCI project MAT-1-4, re-port catalog number PR-350-164500-R03, August 29, 2022.

Distribution of Heat Input from Manual Girth Weld

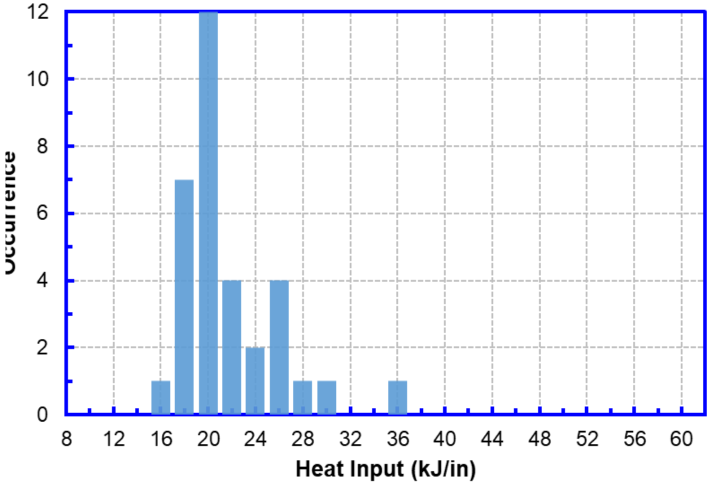
- Manual SMAW with cellulosic stick electrodes
- OD 24” WT 0.344”
- Recorded heat input per electrode, from hot, fill, and cap passes (E8010)

Low heat input



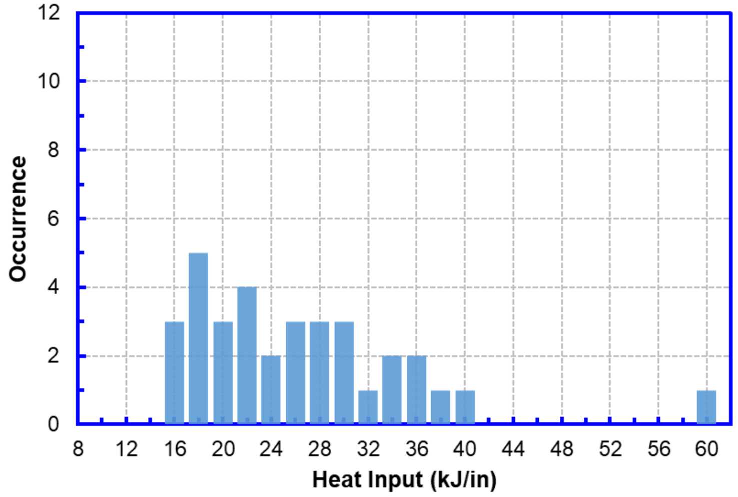
Median: 15.3 kJ/in
Standard deviation: 8.1 kJ/in

Nominal heat input



Median: 20.4 kJ/in
Standard deviation: 4.3 kJ/in

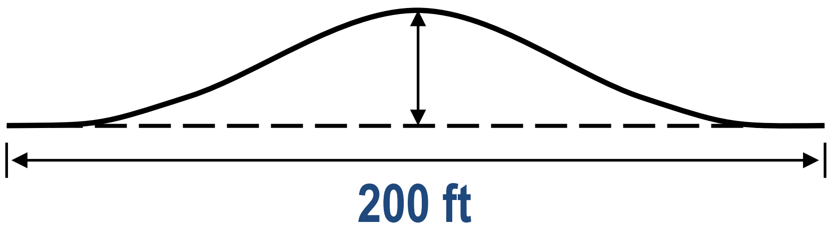
High heat input



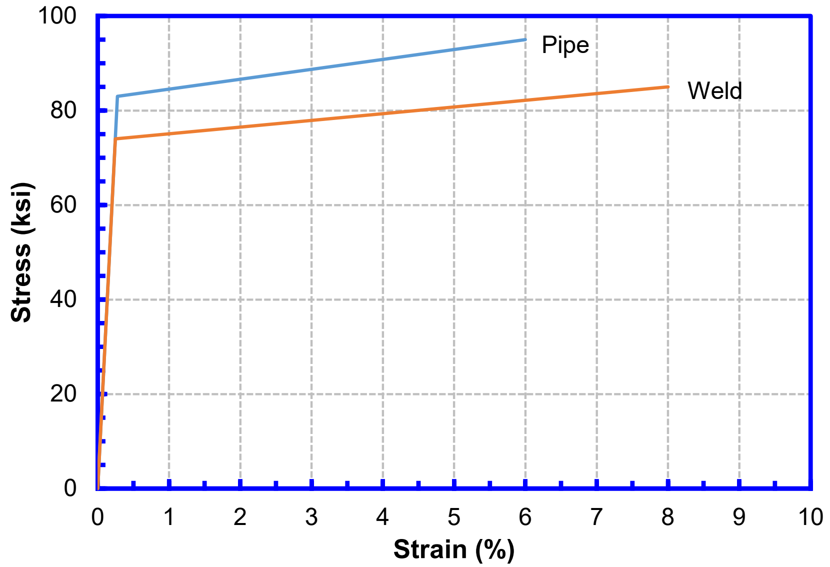
Median: 24.6 kJ/in
Standard deviation: 8.8 kJ/in

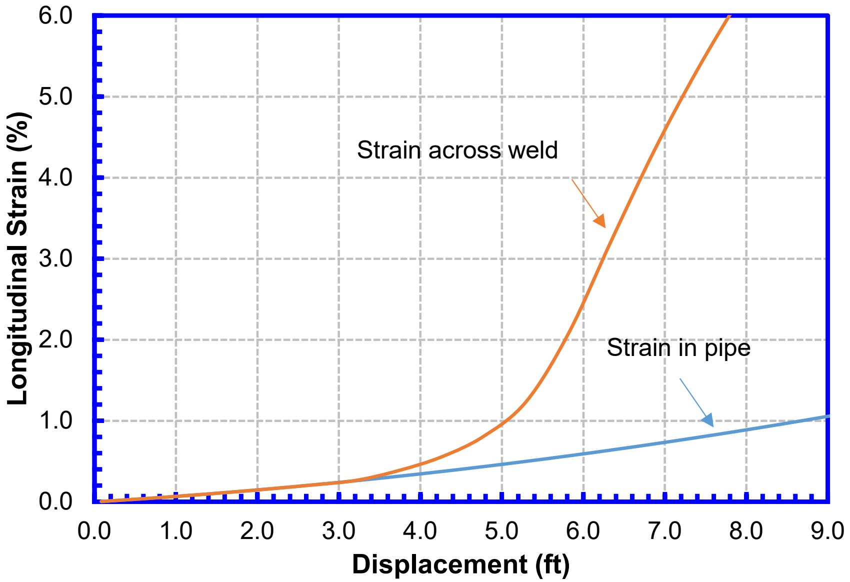
Consequence of Weld Strength Undermatching

- 30” OD, 0.375” WT pipe
- Nominally straight pipe segment
- Longitudinal strain demand generated in the pipe by the lateral ground movement



Material	YS (ksi)	UTS (ksi)
Pipe	83	95
Weld	74	85





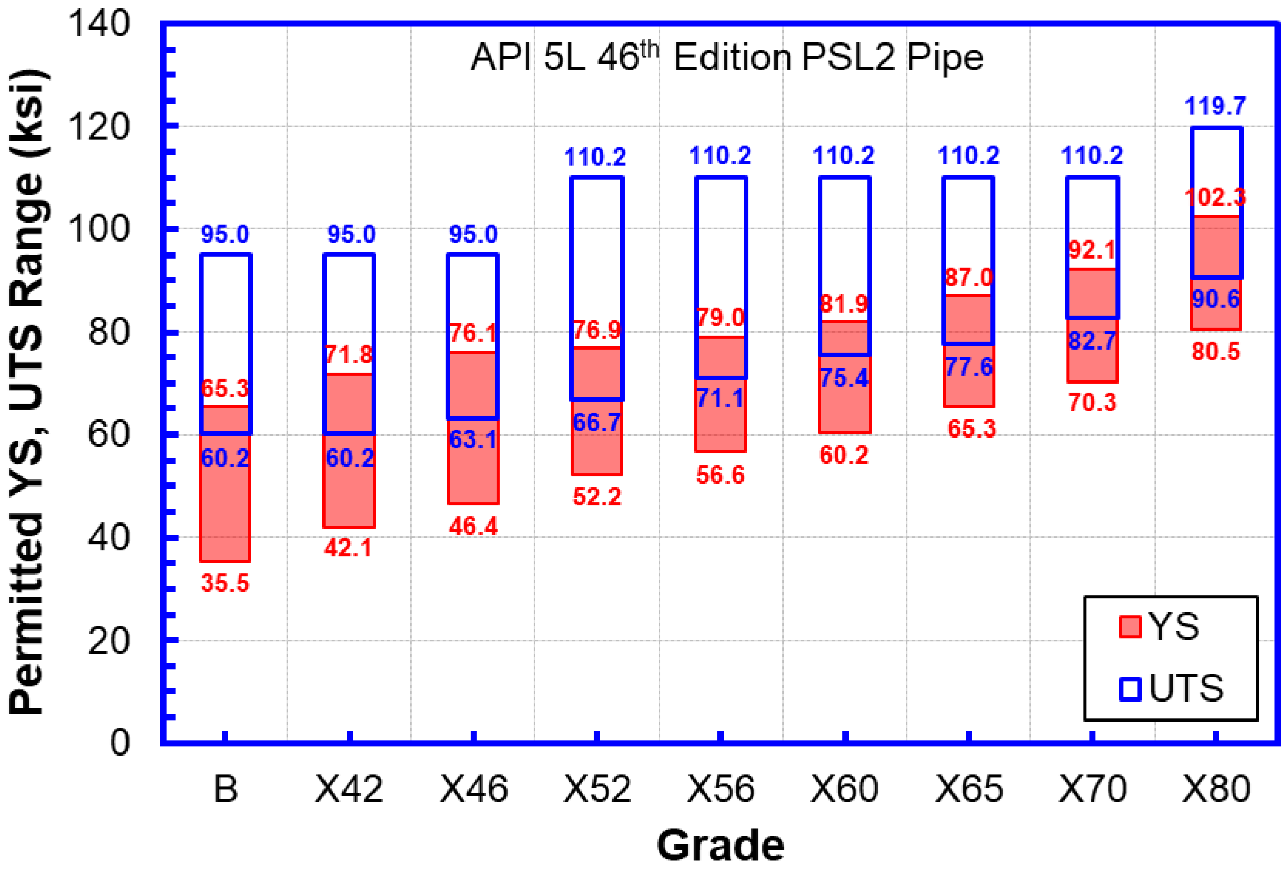
With undermatching weld strength, girth weld starts to take on greater strain than the pipe at a pipe strain of approximately 0.25% (lateral displacement of 3.5 ft).

Tensile Strain Capacity of Girth Welds vs. Field Conditions

- **Tensile strain capacity of girth welds meeting the minimum requirements of standards: 0.25%-0.35%.**
- **Implications of this TSC**
  - Adequate for most individual girth weld locations
  - Some locations can impose strains greater than this level
    - Geohazards
    - Non-geohazards
      - Construction stress
      - Crossings
      - Tie-in

Pipe Strength Has a Role in Weld Strength Undermatching

- The actual yield strength of a linepipe can be significantly higher than the specified minimum.

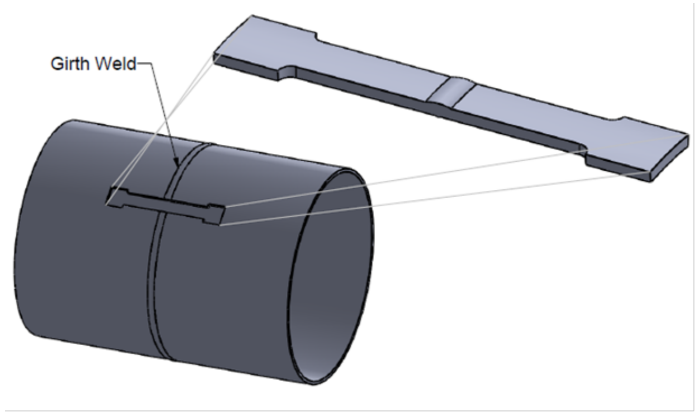


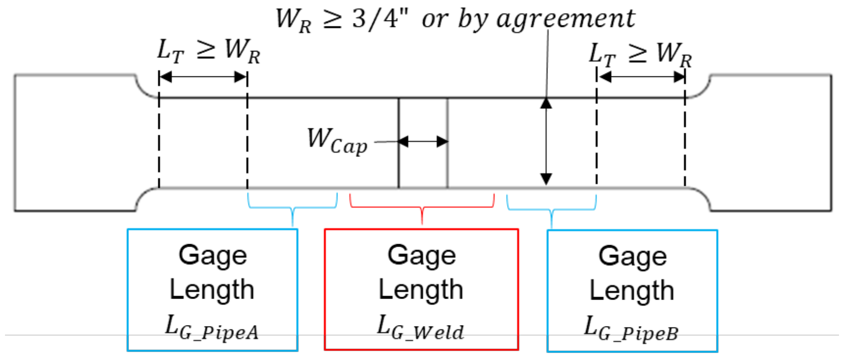
Fundamentally Sound Procedure Qualification – Option 1

- **Qualify a procedure to the actual strength (and other characteristics) of a pipe**
  - The qualified procedure is good for pipe strength up to the qualified strength.
    - A qualified procedure is not tied to a grade, but the actual pipe strength.
  - No break in the weld area in cross-weld tensile test
  - Cons: Difficult to get out the current mindset of qualifying by a grade or a group of multiple grades

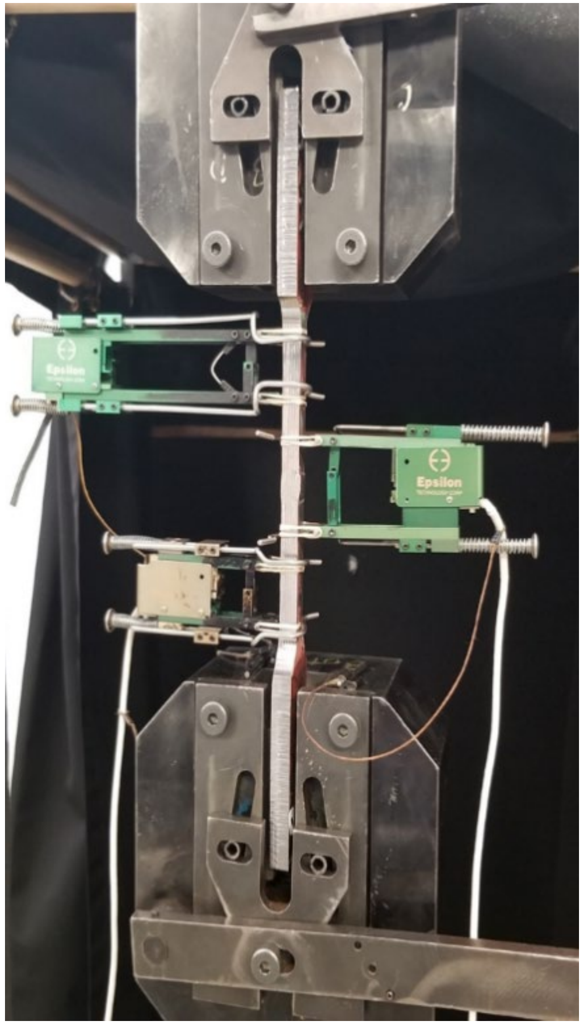
Fundamentally Sound Procedure Qualification – Option 2

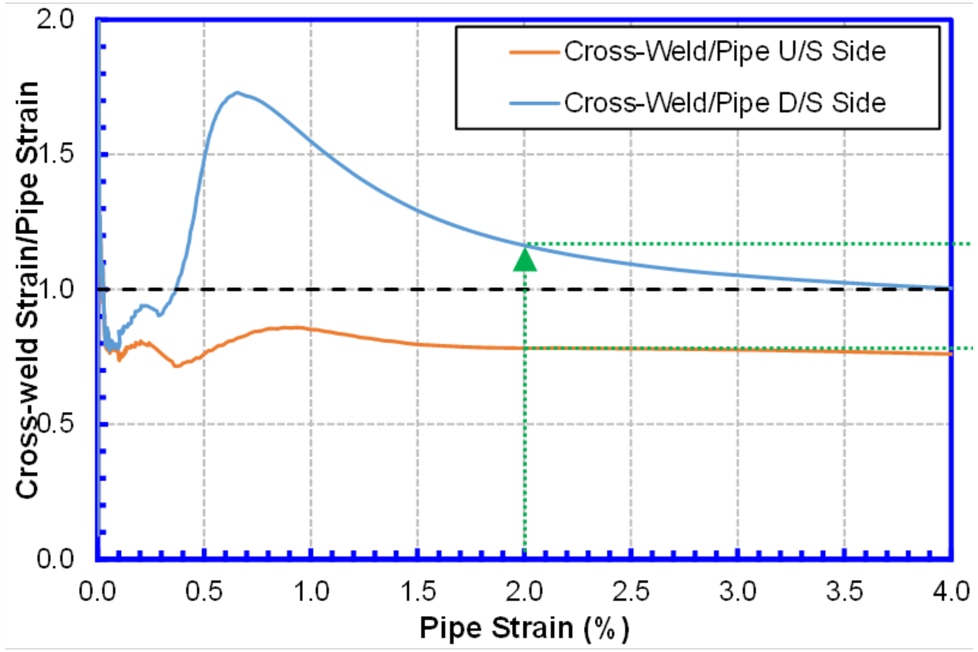
- **Linking qualification requirements with field service requirements**
  - Instrumented CWT tests





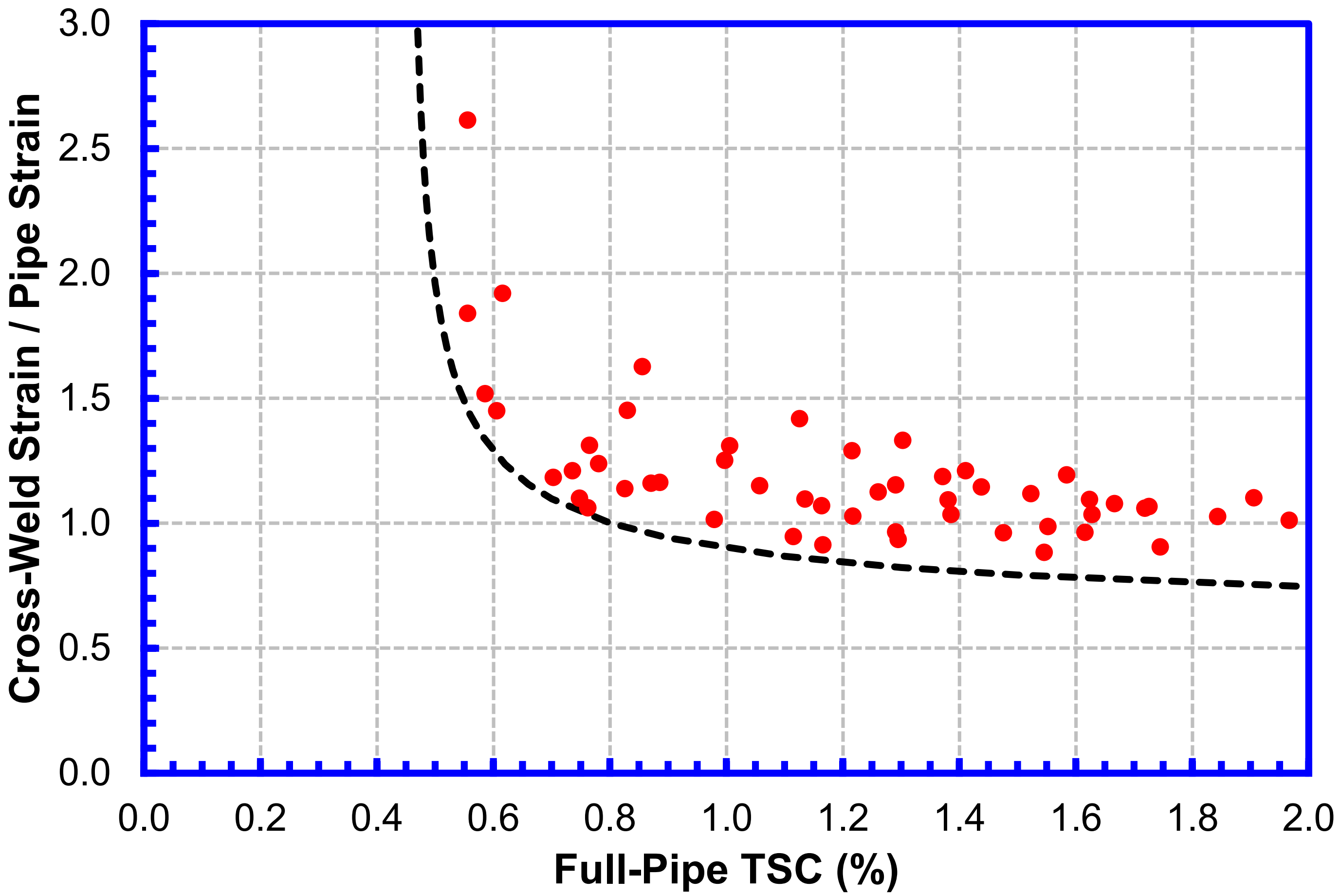
$$W_{Cap} + 0.5" \leq L_{G\_Weld} \leq W_{Cap} + 0.75"$$
$$L_{G\_PipeA} = L_{G\_PipeB} \geq W_R$$





Linking Service Requirements with Qualification Req.

- Relate target TSC with the maximum cross-weld strain ratio



Practical Approach to Procedure Qualification – Option 1

- **Understand likely pipe strength for a grade**
- **Define welding processes and consumables**
- **Define range of heat input**
- **Run confirmation tests**
  - Select right pipes
    - E.g., pipe strength being higher than 67-75 percentile of the possible distribution
  - Use high end heat input of the possible range
  - No failure in the weld area in cross-weld tensile tests

Practical Approach to Procedure Qualification – Option 2

- **Make weld(s)**
  - Define heat input range
  - Use high end heat input of the range
- **Measure weld strength (all weld metal tensile or hardness)**
- **Require weld UTS ≥ SMTS of Pipe + (3-5)×S.D.[1]**
  - E.g., SD = 3 ksi or 20 MPa

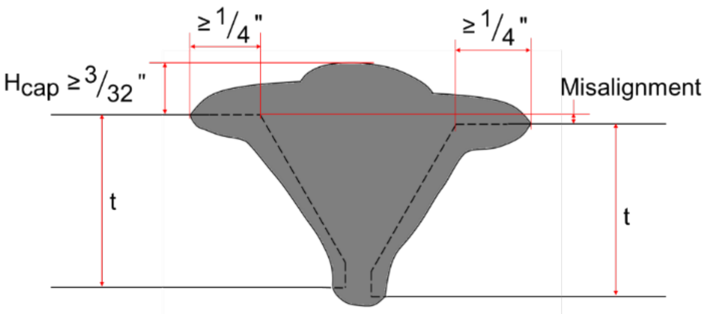
  - [1]Note: this approach is similar to that in EPRG guidelines

Build a Process Selection Table, an Example

- **Selection of parameters: (1) tensile strength and (2) chemical composition**

Pipe Properties	**Pipe UTS (ksi)**	≤ 94		> 94			
	Pipe Carbon (%)	≥ 0.050	< 0.050	≥ 0.040		< 0.040	
	Pipe Pcm	≥ 0.160	< 0.160	≥ 0.140		< 0.140	
Welding options, when the UTS first and then C% or Pcm condition is met	**Filler Metal - Root Pass**	E8010 or E7010					
	Filler Metal - Hot Pass	E8010					
	Filler Metal - Remaining Passes	E8010	E8010	E8010	E9018 E9045 E90T-XX	E8010	E9018 E9045 E90T-XX
	Cap Reinforcement	Regular	Regular	Wide width	Regular	Wide width	Regular
	Target Heat Input*	40 kJ/in max	30 kJ/in max	30 kJ/in max	40 kJ/in max	30 kJ/in max	30 kJ/in max

*Average heat input of all passes excluding root pass



Implementation by Enbridge GTM – Option 1

- **Implementation of Field Construction Specification Changes**
  - Restrict and eliminate the use of fully cellulosic EXX10 consumables for X65 and X70 pipelines
- **Use of low-hydrogen welding consumables/processes with increased weld metal strength**
  - Provide alternative low-hydrogen welding methods:
  - Minimum 90ksi filler material for all X65/X70 materials
  - E8010 consumable for root pass welding (in-process/ong
  - Monitor and apply lower heat inputs
  - Use mechanized GMAW when appropriate

Concluding Remarks

- Gaps in welding procedure qualification requirements have been identified.
- Approaches to improve the requirements have been proposed.
- Linkage to actual pipe properties and field service conditions is important to evaluate the adequacy of procedure qualification requirements.

Acknowledgement

- **Major sources of information**
  - X70 JIP (2017-2020)
    - Contractors: Microalloying, CRES, DNV GL, and Dynamic Risk; PI: Robin Gordon
    - Lead of sponsors: Steve Rapp
  - PRCI project MATH-5-3B (2017-2022)
    - Contractor: CRES; PI: Yong-Yi Wang and Dan Jia
    - Project team lead: Steve Rapp
  - CRES work with individual pipeline companies (2015 to now)
    - Incident investigations (US and overseas)
    - Develop mitigative measures (sometimes as a part of geohazards management)
- **Individuals**
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thank you

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