Levelling our industry knowledge on 'Girth Weld Undermatching'

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Disclaimer and goal

The topic of 'weld strength matching' has produced significant debates locally and internationally

- It is a multidisciplinary topic

Welding and metallurgy

Fracture mechanics

Geotechnical

Risk management

Assurance

Others…

- It tends to drive conflicts between experts from different disciplines; often because the interpretation of technical terms and the focus of discussion differ
- Establishing a common set of definitions is critical to avoid misunderstandings

The aim is to lay down a complex and sometimes polarising topic

- By levelling and disseminating **terminology and assessment principles**
- To support consistent, risk-informed decision-making of existing & future pipelines

This presentation reflects the views of the authors/presenters, not APA

Outline

1. Background

- Industry attention on girth weld integrity increased significantly over the past decade following overseas failures in newly constructed high-strength pipelines.
- There have been **11 reported girth weld failures of pipelines in USA**.
- Most associated with high strength pipe (primarily API 5L X70) welded with cellulosic consumables and reportedly compliant to API 1104 requirements in terms of pipe, weld joint mechanical properties, and defect acceptance limits.
- Primary reported contributors:
  - Weld strength undermatching
  - Heat Affected Zone (HAZ) softening
  - Weld bevel geometry favouring plastic strain along the HAZ

Example of USA failure - Huo Chunyong (TEC 2019)

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Despite no broad dissemination, important findings are available [1-2]:

1. Significant number of failures happened in **tie-in welds;**
2. **No more than one** girth weld failure on any given asset;
3. **Other overseas failures** cited as supporting examples have **not been decisively attributed to the same root causes.**

….Suggests reported failures are specific to **individual welds and conditions, rather than:**

i. Being indicative of systematic problems over the failed assets,

ii. and by extension, systematic in other assets.

[1] Final Report on Literature Review, RP3.2-05A, FFCRC, 2021

[2] USA pipeline girth weld failures: an alternative metallurgical analysis of the literature, Journal of Pipeline Science and Engineering 6 (2026) 100305

1. Background

Australian context

Australian pipelines traditionally welded using manual cellulosic electrode processes.

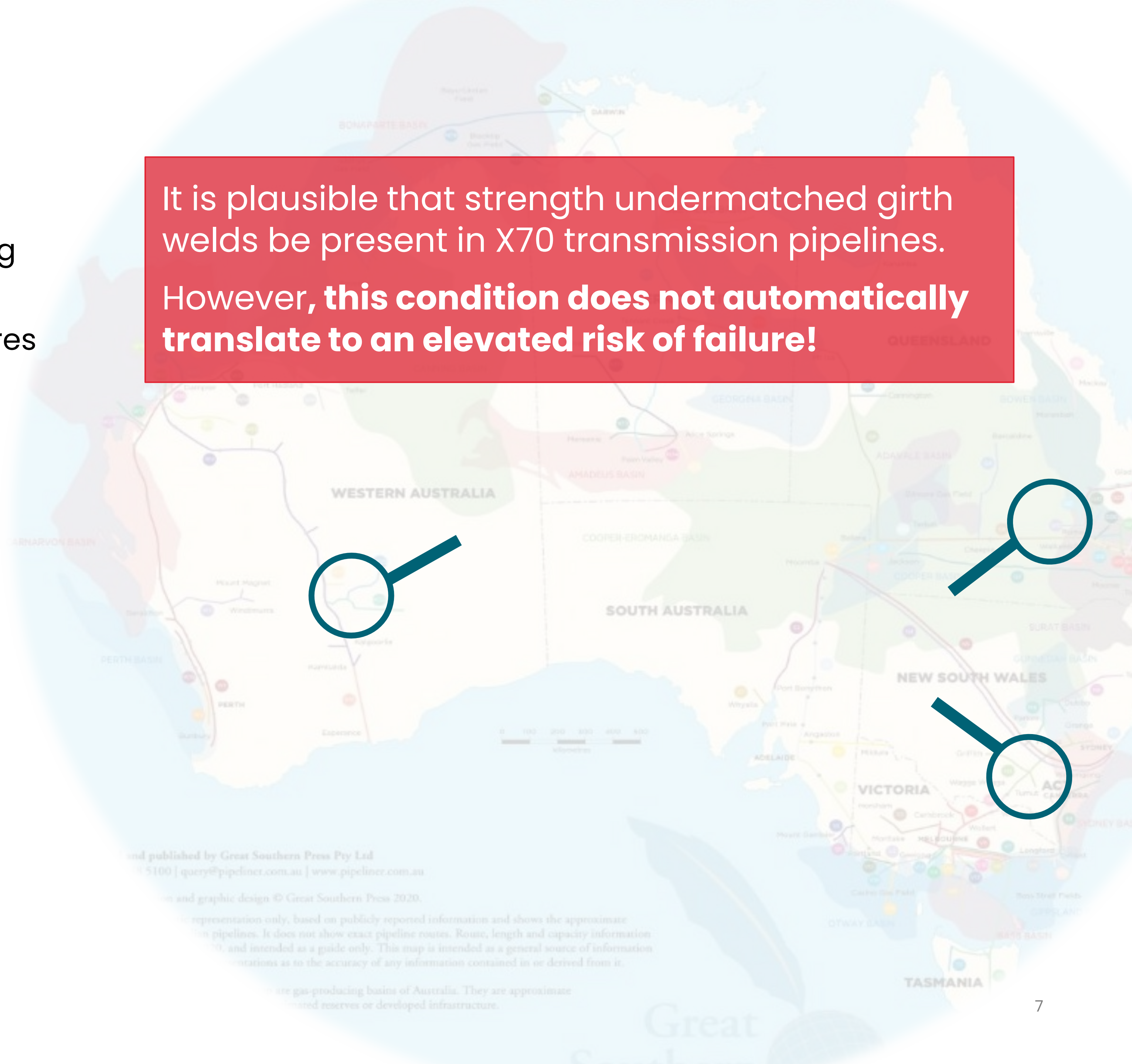
- Direct comparison with reported USA failures is not straightforward. Under AS/NZS2885 framework, our industry has historically applied:

  – Different and more robust **welding qualification** requirements and **construction controls**

- These measures contribute to reduce the **likelihood** and **level** of girth weld strength undermatching in Australian assets.

It is plausible that strength undermatched girth welds be present in X70 transmission pipelines.

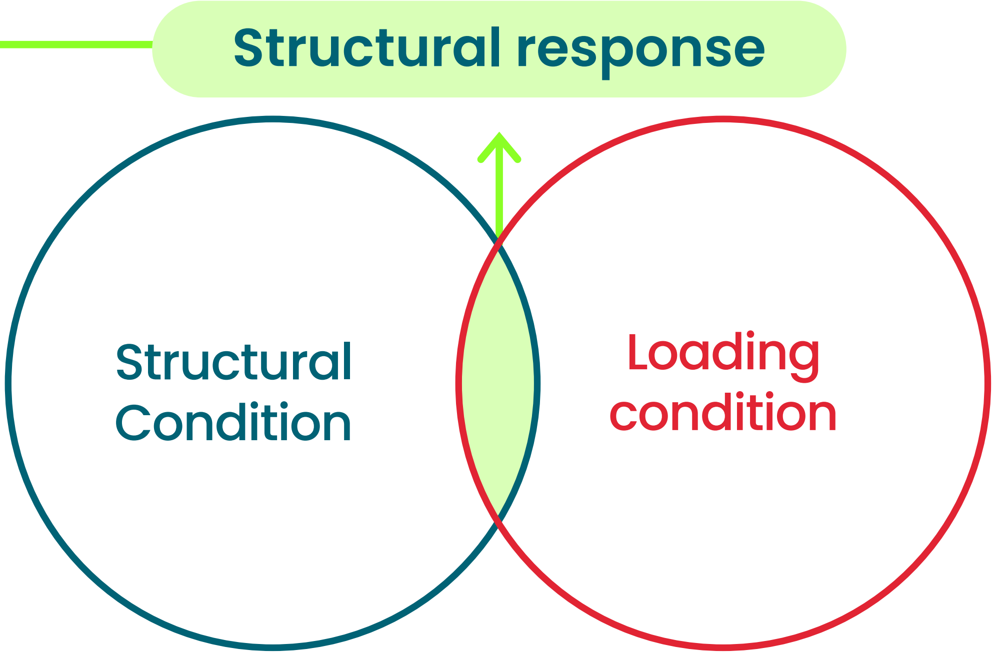
However**, this condition does not automatically translate to an elevated risk of failure!**



2. Assessment principles of a girth weld failure

Under applicable state and territory legislations and the AS/NZS 2885 series, a fundamental obligation of a pipeline licensee → **Assessment of the <u>risk</u> of a girth weld failure**

Risk = Likelihood of failure & Consequence



1. Likelihood of **structural undermatching conditions.** Characterised by a distribution (range, magnitude).

2. Likelihood of **loading conditions** Characterised by another distribution.

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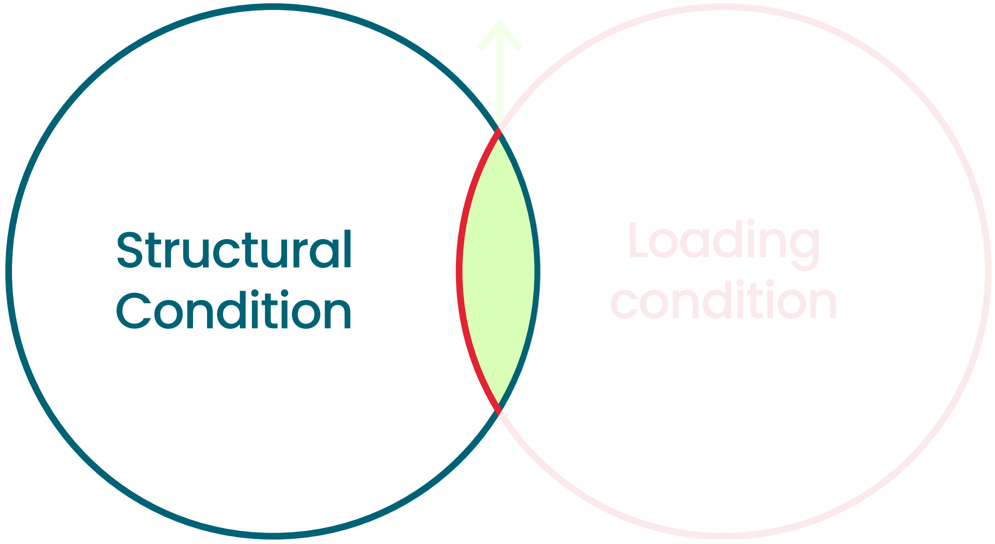
Structural response



1. Likelihood of **structural undermatching conditions.** Characterised by a distribution (range, magnitude).
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3. Definitions

Structural undermatching condition

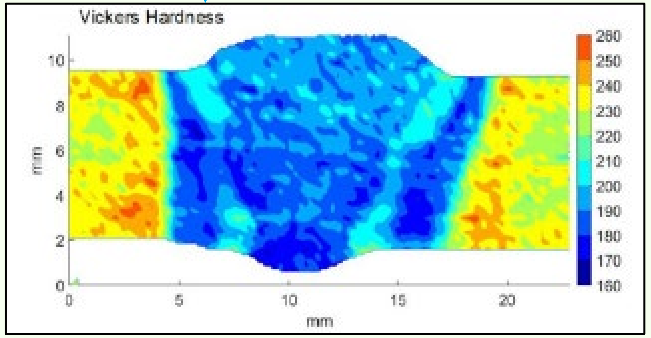
Influenced by compounding effects of conditions that may promote failure in the weld region.

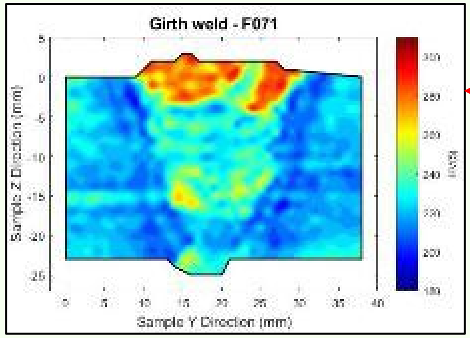
Three primary factors:

1. Strength mismatching

Strength matching: a material property, defined by the relative strength properties of the pipe and weld metal.

- Strength **Over**matching - weld strength is **greater** than that of parent pipes.
- Strength Matching - weld strength approximately matches that of parent pipes.
- Strength **Under**matching - weld strength is **lower** than that of parent pipes.





Strength undermatching:
A long standing and well-recognised feature in high-strength line pipe (≥X70) welded using cellulosic consumables (manual metal arc welding).

Not straight forward… →

Table 3 Tensile properties of X70 base materials and SMAW weld metals

Electrodes	Weld metal YS (MPa)	Weld metal UTS (MPs)	X70 base material YS (MPa)	X70 base material UTS (MPs)	Reference
E6010/E6010	479-512	546-610	487-528	586-611	[9]
E6010/E6010	503-552	569-632	487-528	586-611	[9]
E6010/E6010	509	606	539	601	[10-13]
E6010/E8010	493	617	525	597	[10-13]
⋮	⋮	⋮	⋮	⋮	⋮
E6010/E9010	458-538	605-676	490-503	600-615	[14]
E6010/E9010	530	643	580	632	[10-13]
E7010/E9010	574-584	648-662	472-521	577-620	[9]
E8010/E8010	457 500	587 605	583 613	659 713	[15]
E8010/E10018	586	652	578	624	[10-13]

FFCRC RP3.2-05A: Literature review

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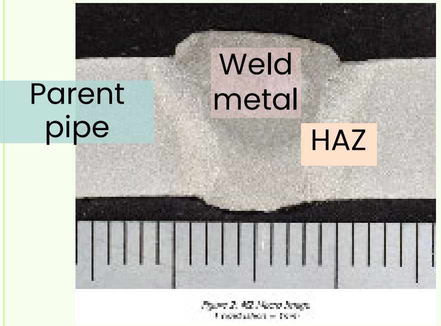


- Weld Joint Strength
  - Parent Pipe Strength
    - Pipe composition
    - Steel & pipe process
  - Weld Metal Strength
    - Consumable comp
    - Parent pipe dilution
    - Welding conditions
  - Heat Affected Zone (HAZ) Strength
    - Welding conditions
    - Pipe Composition
    - Pipe wall thickness

3. Definitions

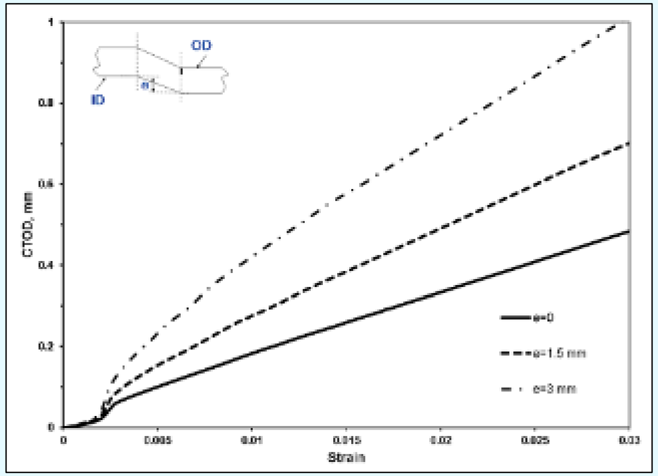
Structural undermatching condition

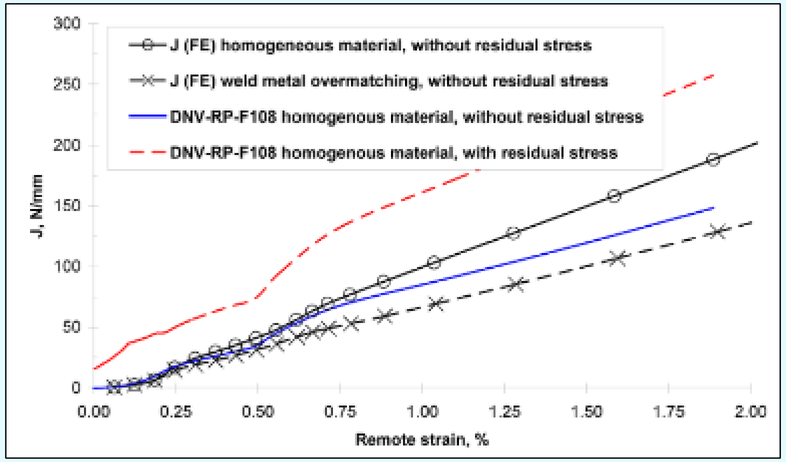
Influenced by compounding effects of conditions that may promote failure in the weld region.

Three primary factors:

1. Strength mismatching
2. Fracture mechanics properties & geometry
3. Nature and geometry of flaws

- **Toughness:** J, CTOD, Charpy
- **Weld geometry:** Misalignment, bevel angle, weld cap & toe
- **Flaws types and size**
    - Surface breaking, embedded,
    - Length, height, cross sectional area a/t ratio
    - Presence of cracks or stress concentration
- **Residual stress**





(left) Misalignment and (right) residual stress influence on toughness demand at girth weld
H. Pisarski, TWI, CBMM-TMS International Conference, 2011

2. Assessment principles of a girth weld failure

Under applicable state and territory legislations and the AS/NZS 2885 series, a fundamental obligation of a pipeline licensee

Assessment of the risk of a girth weld failure

Risk = Likelihood of failure & Consequence

Structural response

1. Likelihood of **structural undermatching conditions.** Characterised by a distribution (range, magnitude).

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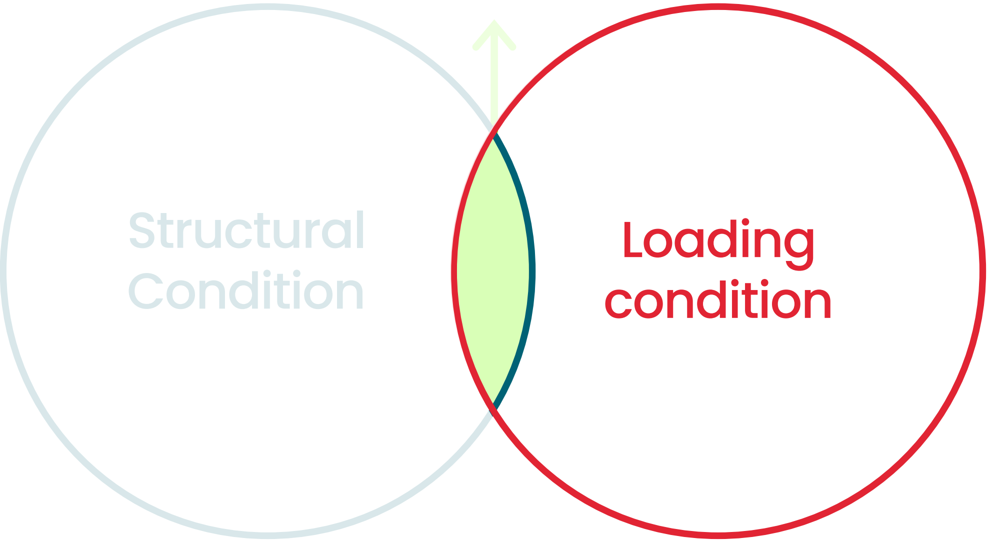
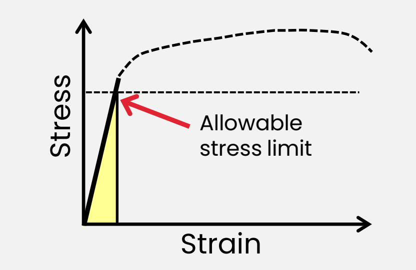


3. Important Definitions

Loading Condition

Stress-Based Design:

Commonly adopted in Australian onshore pipelines due to generally low axial strain demand. Limit loads are defined as fractions of the specified minimum yield strength (SMYS) of the pipe.



Axial stresses in Girth Welds:

During construction:

Axial stresses in completed or partially completed girth welds can occur due to:

- Lifting and lowering-in activities
- Forcing pipe into a trench that does not match the pipe profile
- Inappropriate or uneven support during handling

During operation:

Axial stresses:

- Internal pressure, (significantly lower than hoop stress)
- Normal settlement after construction
- Occasional loads; e.g. ground movement events

3. Definitions

Structural response

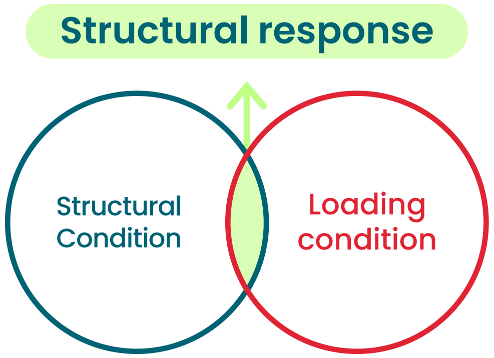
Two failure scenarios (i.e. structural responses):

1 Structural overmatch

The girth weld structurally overmatches ⟷ failure in a region remote from the weld

- Condition may exist irrespective of presence or nature of flaws in the weld region.
- Deformations and failure do not localise in the weld region. Structural response guarantees the loading will lead to straining distributed over the surrounding pipes.

Note:
Structural overmatch can be achieved despite some level of weld **strength undermatching** being present.



Structural undermatch 2

The girth weld is structurally undermatched ⟷ failure in the region of the weld

- Failure **below the design limits = non-compliance.**
  - Non-compliance due to <u>one or several</u> design parameters not satisfactory.
- The weld **may comply if failure occurs above the applicable design limits**. Still, why would the conditions be above the design limits?
  - Lack of understanding of local load demand?
  - Inadequate classification stress-based vs strain-based design?
  - Exceptional circumstances?

2. Assessment principles of a girth weld failure (Summary)

Under applicable state and territory legislations and the AS/NZS 2885 series, a fundamental obligation of a pipeline licensee

Assessment of the risk of a girth weld failure

Assessment methodology to predict operational and occasional loads and determine failure outcome (fail or not)

Gap: structural condition may not be represented in these methodologies

Likelihood of failure

Consequence
Location and environment dependent

Likelihood of Structural undermatching (condition)

There are series of tests as Proxies to evaluate properties

Gap: Current mechanical tests may not be sufficient to determine the overall structural condition (under or overmatching)

1. Strength undermatching

2. Nature and geometry of Flaw

3. Fracture mechanics properties & geometry

Likelihood of Loadings events

- Axial stress
- Strain demand
- Assessed by data and models

Assessment methodology from geotechnical models (Ground movement, river crossing, climate variability).

Gap: reliance on geotechnical consultants.

4. Control principles – Practices from design to long-term monitoring

Line pipe specification

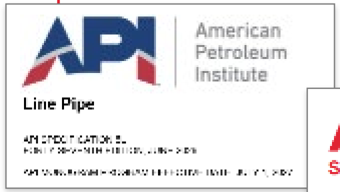
- Manage pipeline strength to facilitate overmatching with consideration of longitudinal tensile strength (TS)
- Specify TS and toughness in the longitudinal direction in both bare and coated condition (understand & account for strain ageing).
- Know the properties of the production

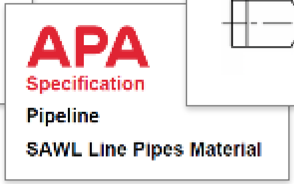
Welding procedure qualification & Construction

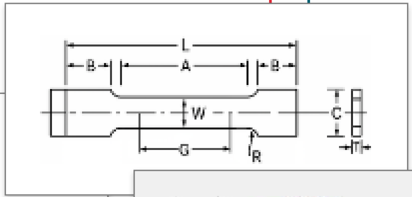
- Select pipes with actual strength in the upper end of the range.
- Consider supplementary test (e.g. All weld metal tensile, SENB, J-curve) for all pipeline welding procedures using pipe ≥ X60 grade.
- Cross-weld tensile tests with cap and root removed by dressing. If not removed, the test piece shall break in the base metal.
- Use of mechanised welding for high strength steels pipelines.

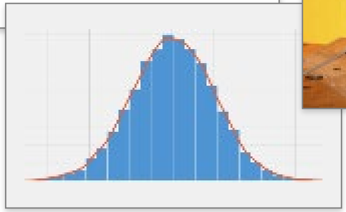
Existing assets

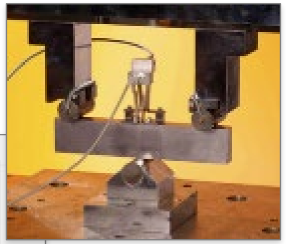
- Geohazard management
  - Uplift internal geotechnical capability, including hazard data management and geohazard program development.
- Prioritisation of assets using assessment principles (likelihood of structural undermatching & likelihood of loading events)
- Perform supplementary mechanical testing and deploy additional monitoring where required.

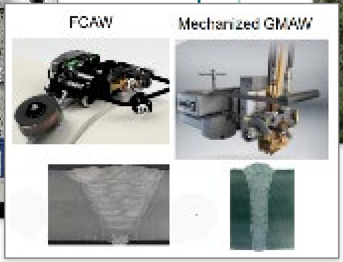

API American Petroleum Institute
Line Pipe

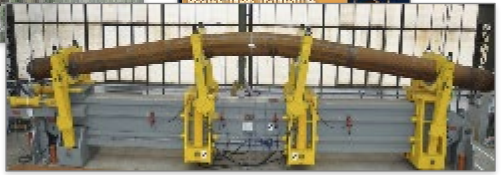

APA Specification
Pipeline
SAWL Line Pipes Material







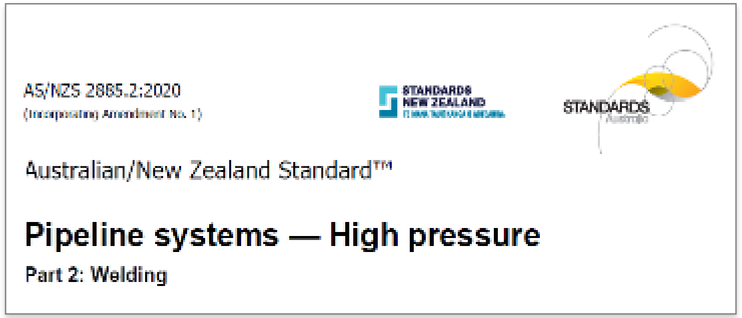




5. Next

AS/NZS 2885.2 – ME28.2 Subcommittee

- Working group “Girth Weld Strength Matching” to review the current requirements and research findings
- 2 years project


AS/NZS 2885.2:2020

STANDARDS NEW ZEALAND

STANDARDS Australia

Australian/New Zealand Standard™

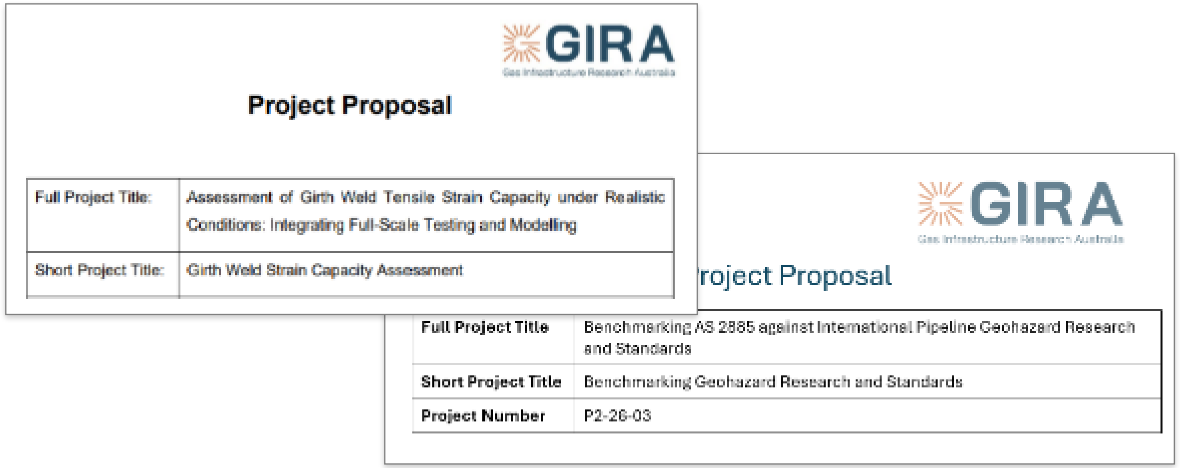
Pipeline systems — High pressure

Part 2: Welding

AS/NZS 2885.3 – Amendment 1: 2026

Gas Infrastructure Research Australia (GIRA) research projects:

1. *“Assessment of Girth Weld Tensile Strain Capacity: Integrating Full-Scale Testing and Modelling”* (3-years project) – WG1
2. *“Benchmarking AS 2885 against international pipeline Geohazard Research and Standards”* (6-months) – WG2


GIRA

Gas Infrastructure Research Australia

Project Proposal

Full Project Title:	Assessment of Girth Weld Tensile Strain Capacity under Realistic Conditions: Integrating Full-Scale Testing and Modelling
Short Project Title:	Girth Weld Strain Capacity Assessment

GIRA

Gas Infrastructure Research Australia

Project Proposal

Full Project Title	Benchmarking AS 2885 against International Pipeline Geohazard Research and Standards
Short Project Title	Benchmarking Geohazard Research and Standards
Project Number	P2-26-03

Thank you

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