EPRG-PRCI-APGA

23rd Joint Technical Meeting

Edinburgh, Scotland • 6–10 June 2022

P231: Preparations of the full scale H_2 fatigue crack growth test

6th June 2022

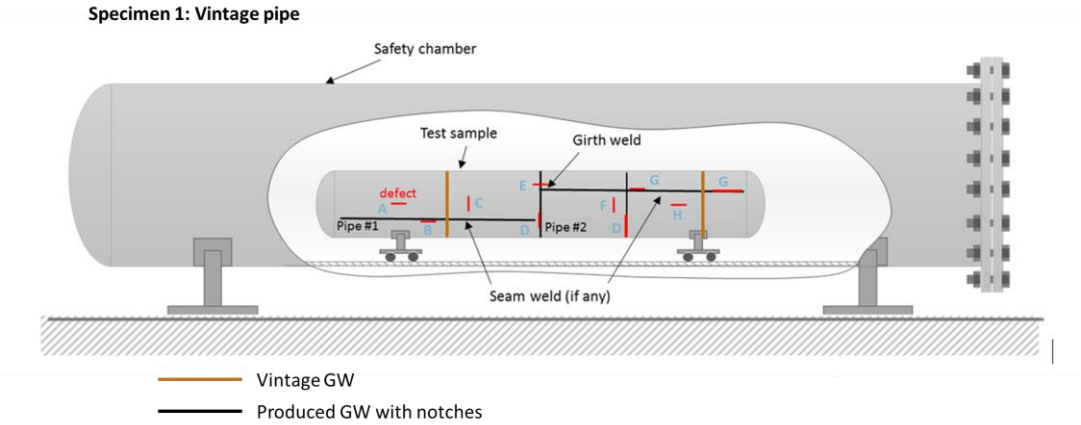
Scope of this presentation

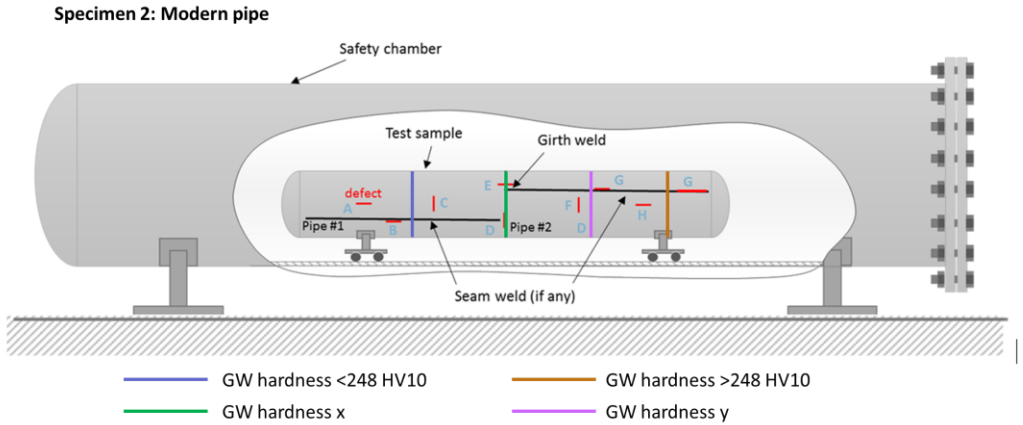
Preparation of the test on the modern pipe:

- Scope
- Material selection
- Test setup
- Girth welding
- Sizing of the notches
- Notching trial
- Environment control (Oxygen, Humidity)
- Residual stress measurement
- Crack initiation (nucleation)
- NDE monitoring of crack growth
- Test execution planning

Scope for full scale tests:

- Effect of hardness over the ASME limit (Hv10>248) on material performance (fracture/fatigue/ductility) in gaseous H2
- Material performance Δ between modern steels + AUT welding vs vintages steels + cellulosic welding,
- Fatigue behavior from small scale tests via fracture mechanics vs full scale behavior for all the defects,
- Estimate of the fracture behavior of seam weld (after fatiguing to failure), compared to the prediction via fracture mechanics.



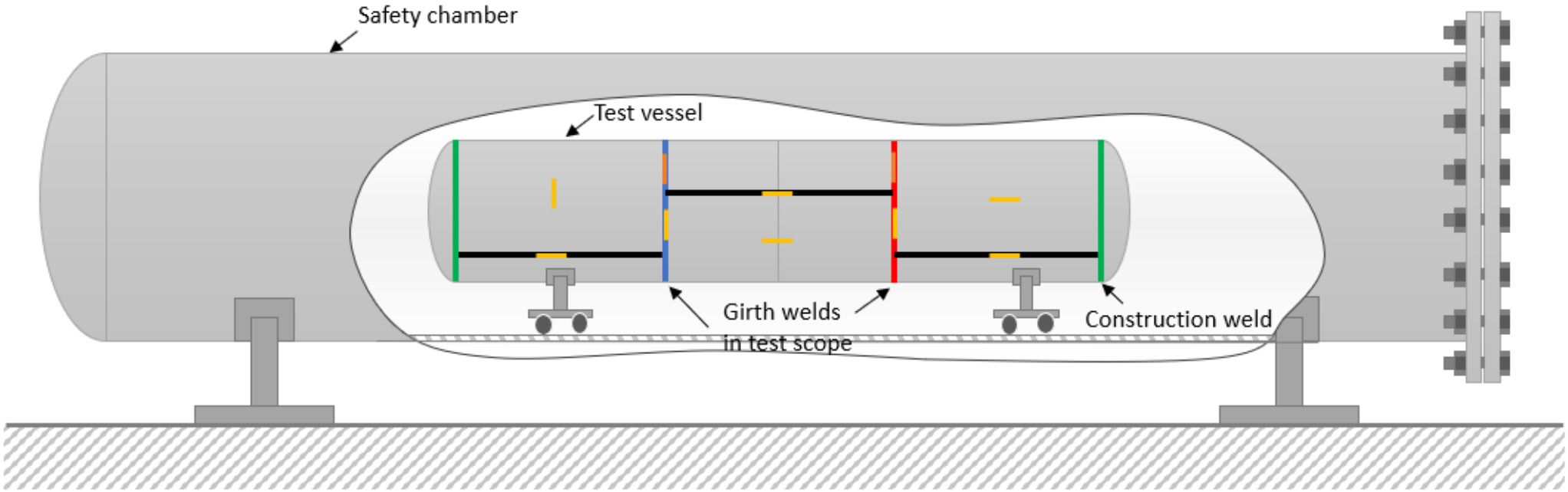


Material selection

- European pipeline modern materials
  - To meet the lower Y/T ratios as given in the Annex A of ISO 3183 for European on-shore pipelines
    - Low carbon (0.07 ~ 0.09%)
    - Polygonal/equiaxed ferrite structure with pearlitic banding (C >0.07%)
  - Pearlite areas can act as gathering sites for hydrogen atoms → HIC

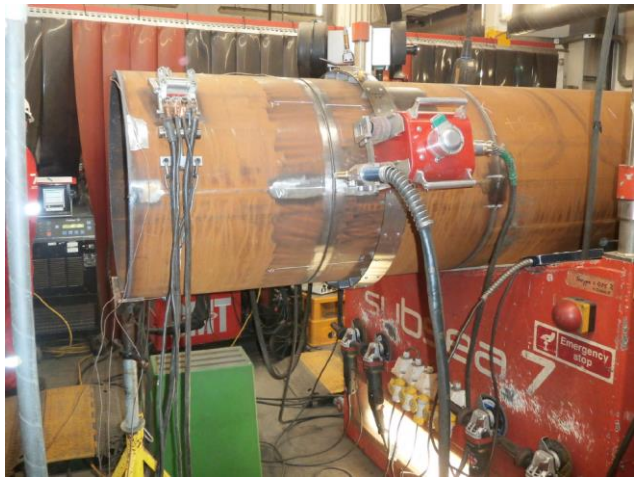
Parameter		Specimen #1 (Vintage)	Specimen #2 (Modern)
Pipe Material	Diameter	26"/DN650	**28"/DN 700**
	Wall thickness	11,13 mm	**17.5 mm**
	Grade	X60/L415	**X70/L485M**
	Seam weld	SAW	**DSAW**
	Production Date	1970's	**2021**
Girth weld	Welding Process	1. Existing vintage 2. Manual cellulosic	**Mechanized; normal and high hardness**

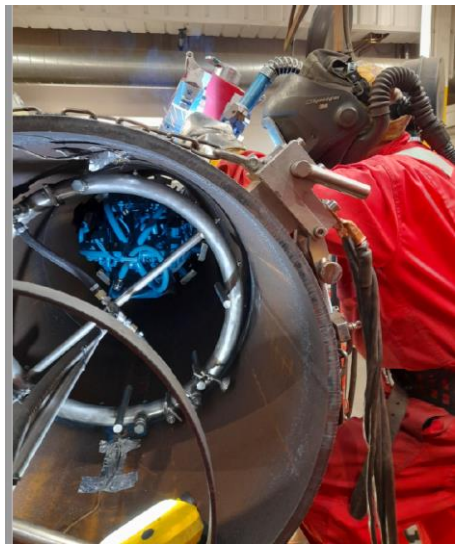
Test setup: modern pipe

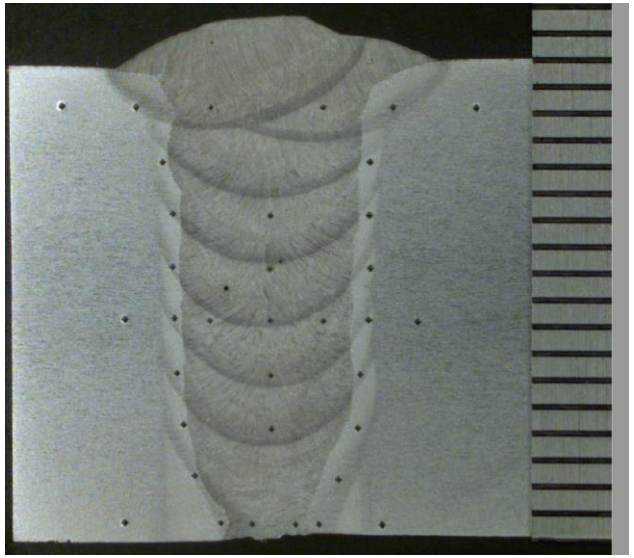


Girth welding

- Normal and high hardness girth welds made by Subsea 7
  - Modern welding: narrow gap (2°)
  - WPS developed & validated (PQR completed)
  - (very) Lean pipe chemistry → HAZ hardness only around 220 Hv despite forced cooling
  - Controlled the weld consumable and heat input to achieve a normal hardness (~250 Hv) weld metal and a high hardness (~300 Hv) weld metal with the accelerated interpass cooling (middle pic)
  - Aim to also create a lack of penetration (LOP) flaw in weld root for final welds







Sizing of the notches

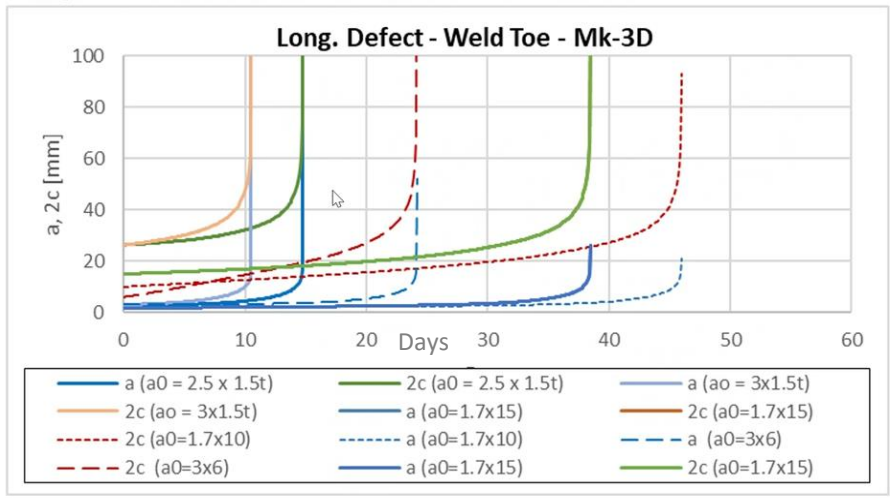
- Based on the ECA calculations
  - Calculations done using the actual FCGR and FT data from a representative pipe material
  - Range of notches considered: 1.7mm ~ 2.5 mm deep
  - Some findings below :

Boundary conditions for the notch sizing:

- ECA calc'd notch to fail within 3 months of net cycling
- Crack growth must be discernible by TOFD in 2 week inspection intervals
- Starter notch should be no smaller than the N10 notch (1.7 mm)

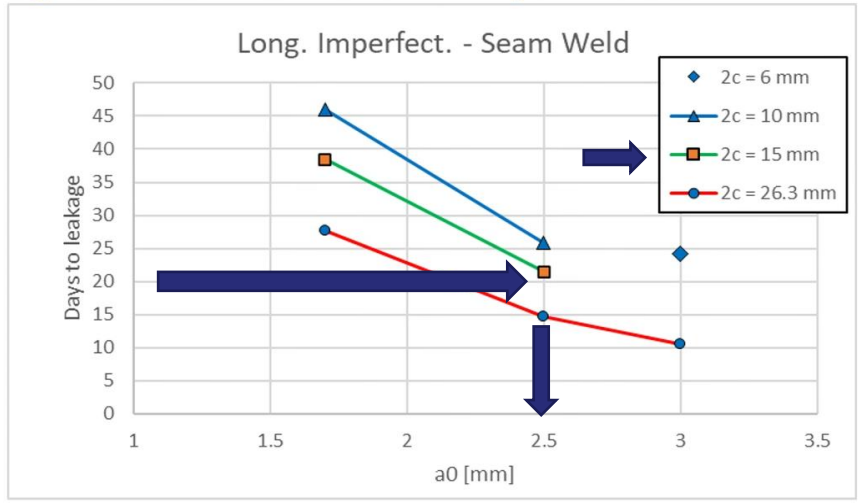
Results

Long. Defect – Notch in Seam Weld – Recent Calculations



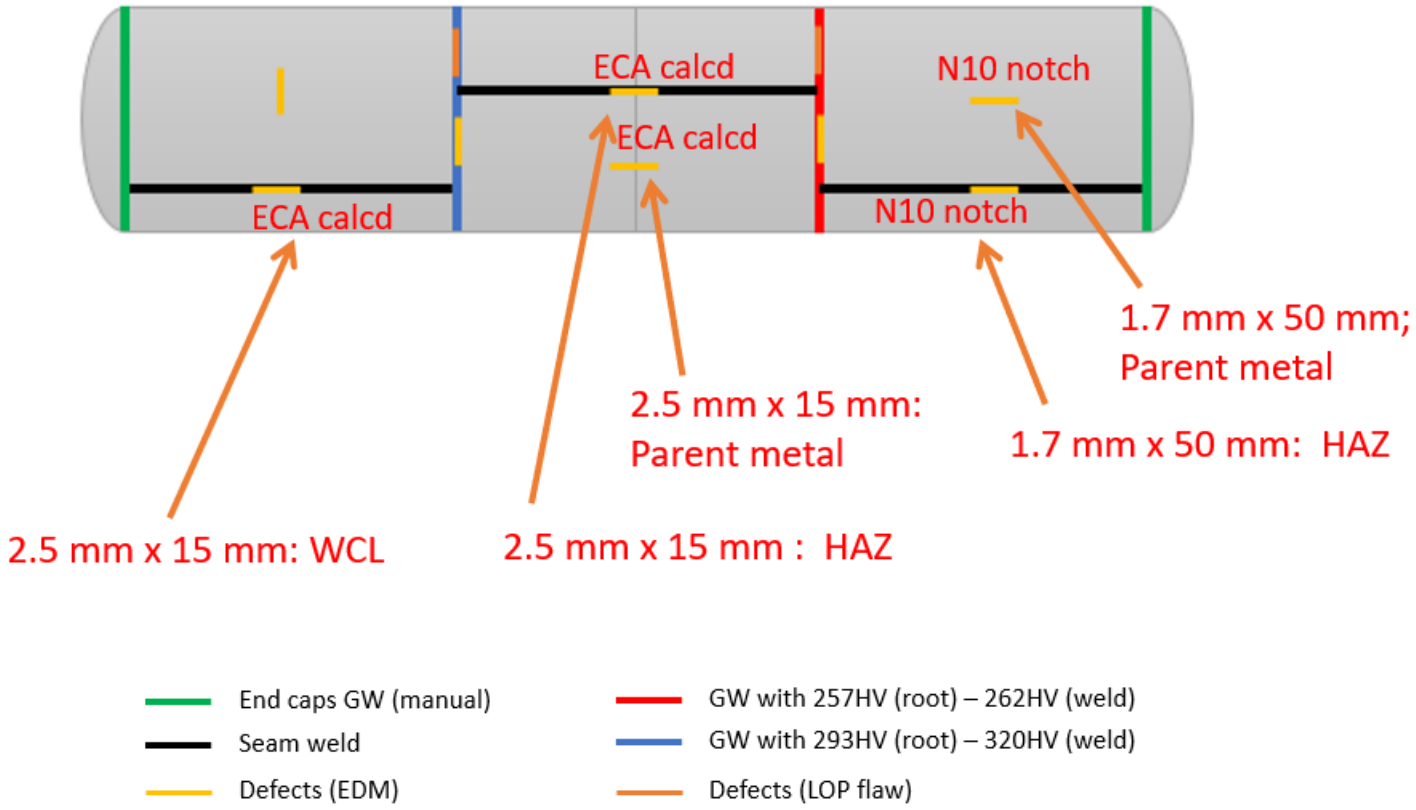
Results

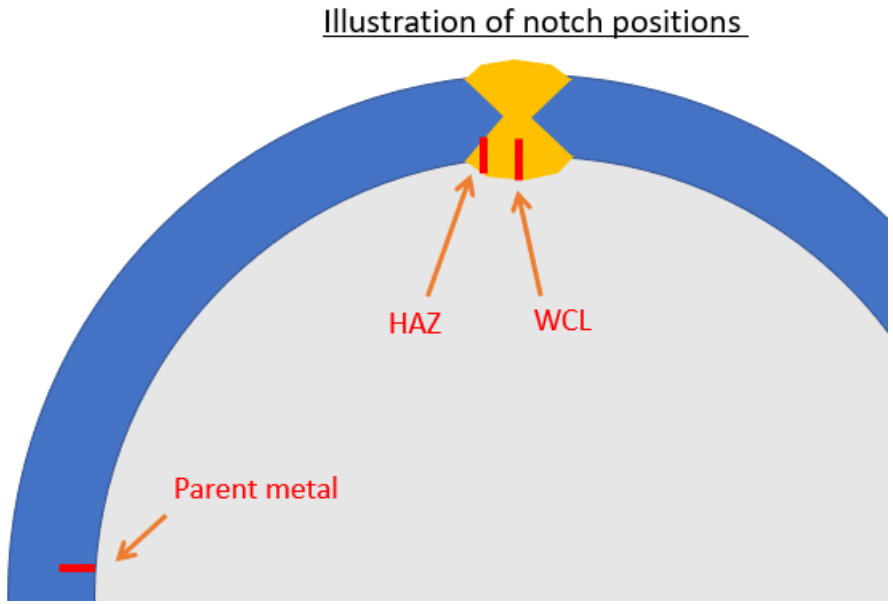
Long. Defect – Notch in Seam Weld – Summary various calculations



Sizing of the notches

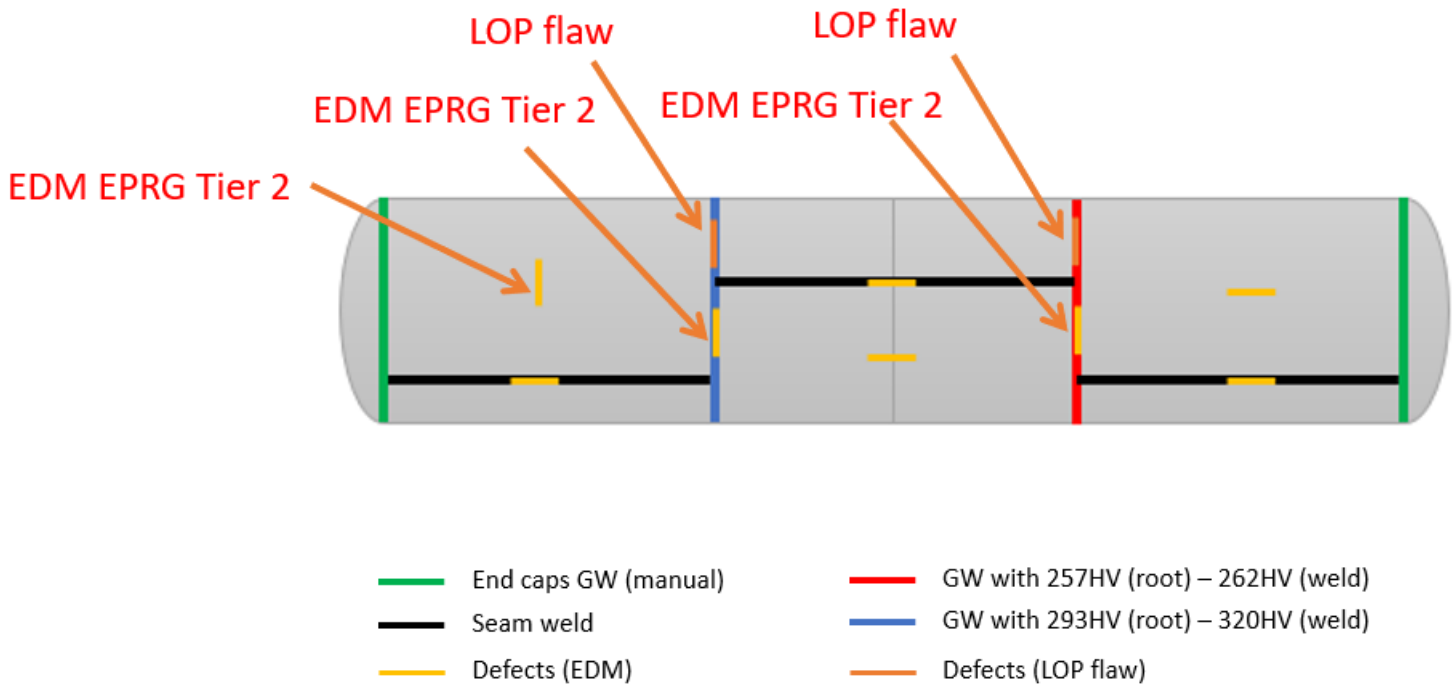
- Current proposal for the **longitudinal** notches :



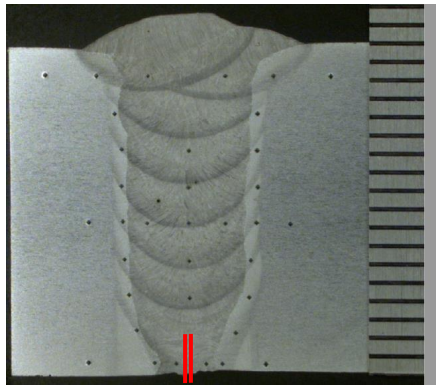


Sizing of the notches

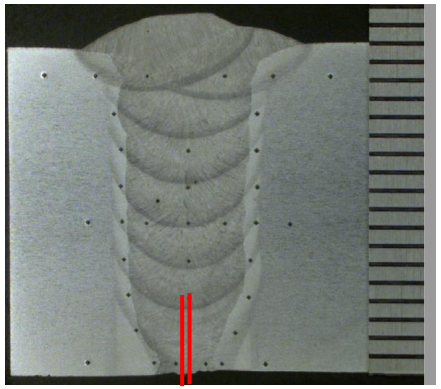
- Current proposal for the **circumferential** notches:



LOP flaw positioning:



EDM notch positioning:

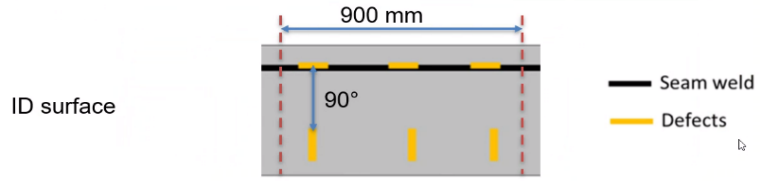


Notching trial

- EDM technique used
- 3 circumferential notches
- 3 longitudinal notches
- Aim is to confirm repeatability and to measure the notch geometry with sectioning

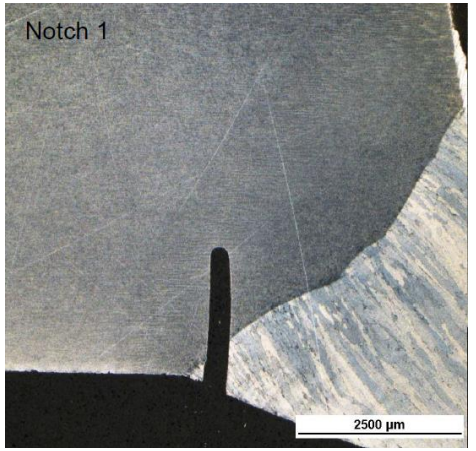
Sample for Notch trial

- Modern pipe OD 711mm WT 17.5mm with longitudinal seam weld
- Sample length about 1 m



Defect type		Defect size			Number of notches to be performed during trial
		ai (mm)	2ci (mm)	Width (proposal)	
Circumferential	Base metal	4 mm	5 WT = 87.5 mm	0.3 mm	3
Longitudinal	Seam weld toe	3 mm	1.5 WT = 26.3 mm	0.3 mm	3

Notch depth (ai): constant along notch axis, except at the edges were rounding radius will be agreed with the workshop.



Environment control

- Target to keep O_2 as low as practical (<< 10 ppm)
  - O_2 is one of key elements affecting fatigue crack growth
  - EPRG test aiming at O_2 'free' FCG test
- Target to keep H_2O < 5 ppm
  - Excessive H_2O may interact with H_2 in a similar way as O_2 (+ hydrate concerns) hence controls put in place
- Plan:
  1. Extensive purging with N_2
  2. Fuel cell ISO 14687 compliant H_2 source
  3. Periodic measurement of O_2 levels at low pressure using a vent line → possible sensor was found

Oxytrans II

Oxygen Transmitter

Figure 1: Oxytrans-II

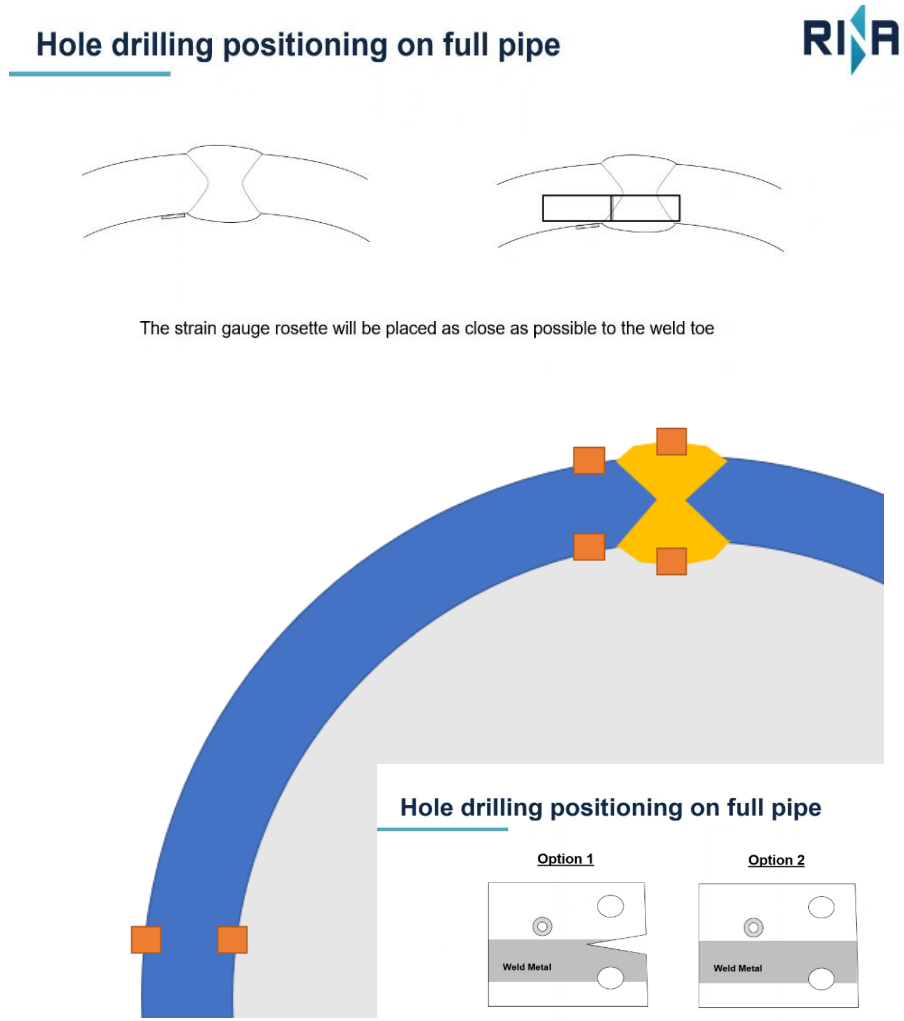
Resolution	0.1 ppm < 0-100 ppm 1 ppm at 0- 1000, 0-10000ppm 0.1% for 25%
Digital Output	HART Communication
Load	Typical 470 ohm
Pressure	Max 10bar (flow through)

Residual stress measurements

- Some data received from Europipe (historic) and Liberty steel
- Some literature data found
- ECA calculations so far assumed WRS at ½ Yield value

- Plan to do shallow hole drilling measurements on the actual pipe at
  - Pipe body (notch location)
  - Parent metal near seam weld toe
  - Seam weld centerline
- Also plan to do the same measurement on the CT sample coupons
- Also plan some deep hole drilling in the seam weld centerline location on the full pipe

- Important as this feeds into post test interpretations of the fracture event and into the fatigue crack growth interpretations



Upcoming activities

- **Crack initiation at a machined notch →**
  - Using round notched tensile samples
  - Aim is to understand the duration of crack nucleation at a notch as a function of delta stress & notch geometry

- **NDE monitoring of crack growth →**
  - TOFD measurements are planned for every 2 weeks.
  - Aiming for accuracy on flaw depth measurement of ± 0.3 mm (requirements on consistency)
  - Preparing the inspection work procedure with the local NDE contractor
  - Exploring opportunity with Applus RTD to attach some probes permanently to some notches for real time measurements.

Test site

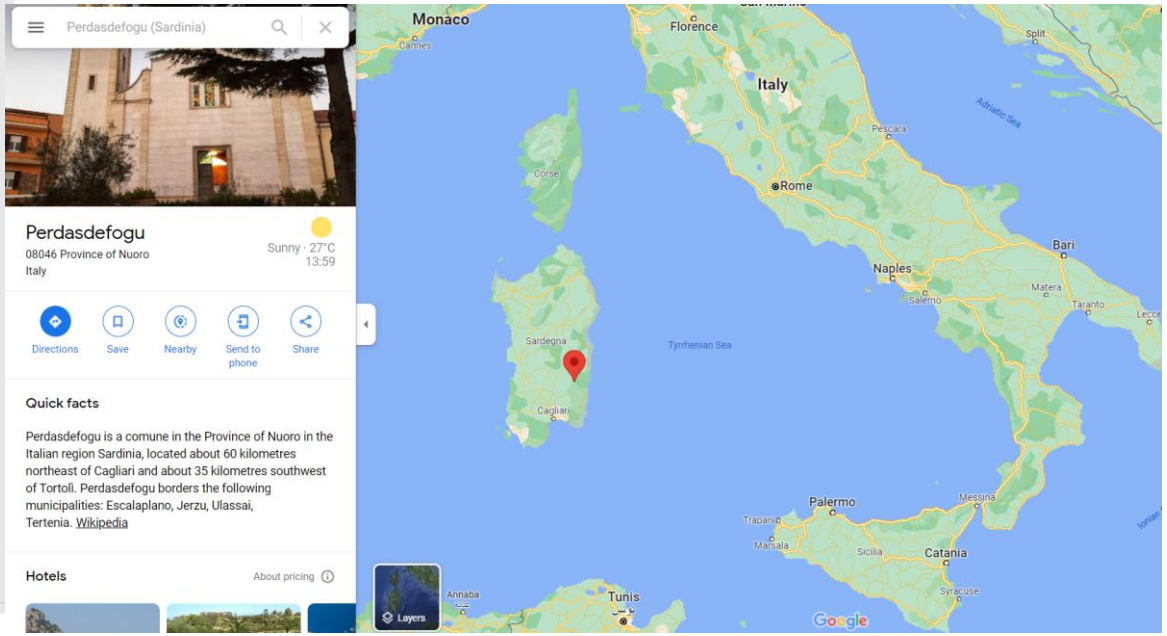
- CSM-RINA confirmed Perdasdefogu (Sardinia)

Test site location

RINA

Location	PROs	CONs
Perdasdefogu (Sardinia)	• Easier permitting • Easier heavy works • Easier safety • Safety chamber already there	• Distance from some Suppliers • Travel for RINA people • Possible stop due to military activities*
Roma	• Easier access from Suppliers • No travel for RINA people • No stop due to military activities	• More difficult permitting • More difficult heavy works • Safety more complex • Safety chamber to be moved from Sardinia

*. This would NOT imply long stop during summer and Christmas periods: these stops are for explosive related activities (bursting) which are nor foreseen in EPRG Prj 231



Planning for the test execution

- Main steps
  - System purging with N_2 and pressurisation up with H_2
  - Fatigue cycling with stoppages every 2 week , decompression (venting) and TOFD inspection (total ~3 days)
  - Start fatigue cycling at ΔP of HOLD % (for nucleation)
  - Then reduce to ΔP of 30% for the initial phase of flaw growth
  - Then reduce to ΔP of 25% and 20% for final stages of crack growth
  - Fatigue cycle until leakage (failure) in one of the defects → STOP.

Informed by live ECA re-calculations

Schedule

- Test vessel preparations: June ~ August
- Test plant preparations: June ~ September
- Fatigue test start: Expect to be October
- Fatigue test duration: Targeting 4 months, but may run longer

Thank you for your attention.