Internal corrosion monitoring using helical ultrasonic waves

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Presentation Outline

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2. Background
3. Methodology
4. Helical Guided Ultrasonic Waves (HGUW)
5. Corrosion assessment
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   II. Tomography
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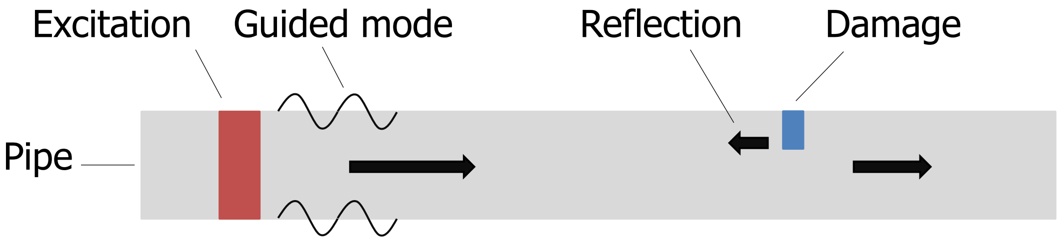
1. Objective

- The main objective of this work is to a develop a systematic approach by which the underlying structural health condition of steel pipes could be assessed using non-destructive methodologies.
- Overall, it is proposed to use a novel class of sensing system, helical guided ultrasonic waves (HGUW) and advanced data processing techniques for supporting corrosion diagnosis and decision-making.

2. Background

Conventional guided wave inspection [1,2]

- Ring of transducers (>32) operating in pulse-echo or pitch catch configurations



- Low frequency (<100 kHz)
- Long range inspection (~ 50m)
- Effective in localizing large & low-contrast defects.

Limitations

- Large number of sensing units
- Limited tomographic capacity (low frequency)

(1) Alleyne et al., 2004 , (2) Lowe et al., 2006

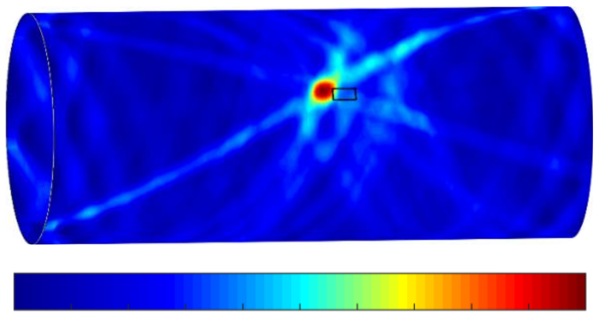
3. Methodology - NDE/SHM

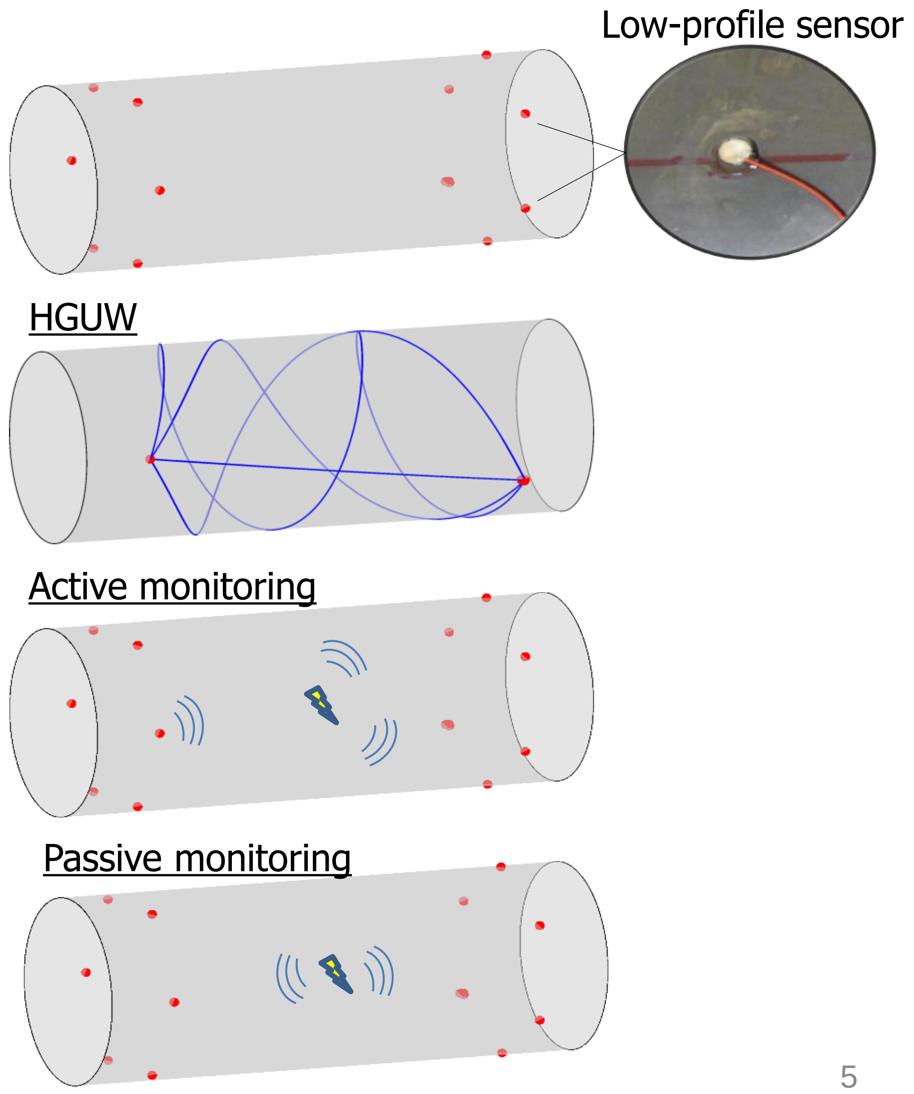
Structural Health Monitoring (SHM)

- Instrument the pipe with sensors
- Utilize helical guided ultrasonic waves (HGUW)
- Active monitoring (Guided waves)
- Passive monitoring (Acoustic Emission)
- Continuously attempt to localize potential damages

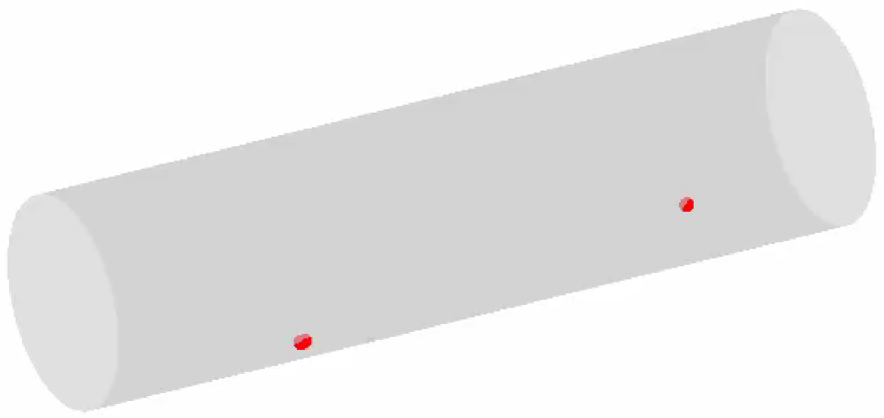
Non-Destructive Evaluation (NDE)

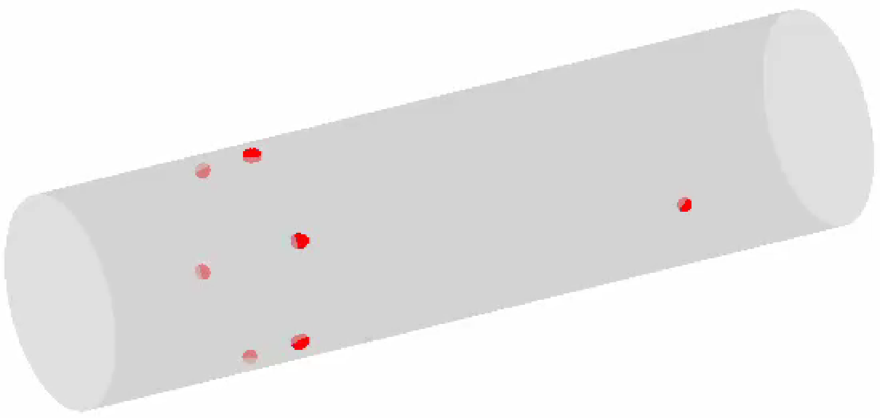
- Locally perform a wall thickness evaluation





4. Helical Guided Ultrasonic Waves (HGUW)

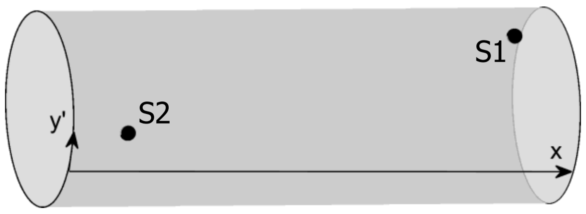




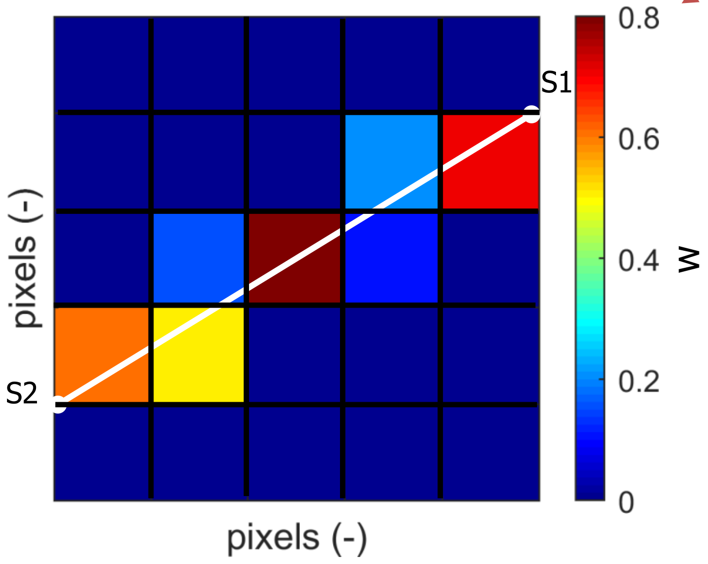
5. Corrosion assessment - Localization

Algebraic Reconstruction Technique (ART)

- Handles sparsity extremely well
- Fast & reliable



ex. Discretize in 25 pixels



Implementation

$$A_{(m\times n)}x_{(x\times 1)} = d_{(m\times 1)} \qquad (6)$$

A = weight of each pixel

d = damage coefficients

x = vector of unknowns

m = number independent equations (helical paths)

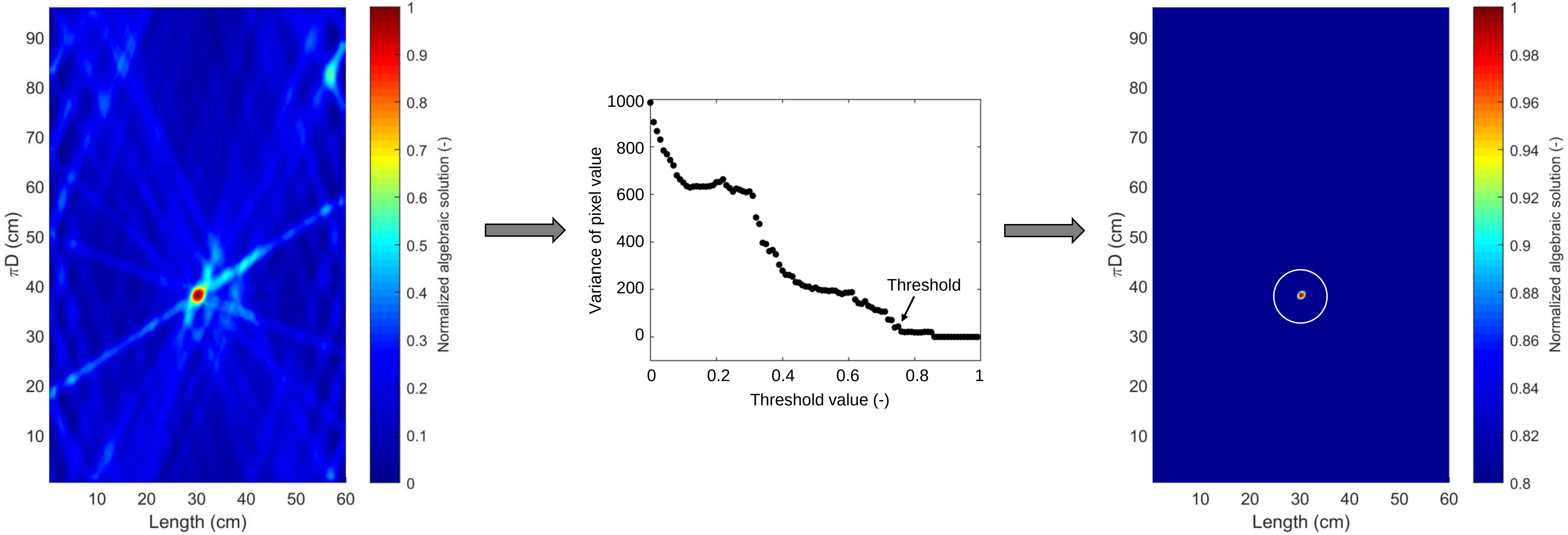
n = number of pixels

$$A_{(mxn)} = \begin{bmatrix} w_{1,2}^{1,1} & w_{12}^{1,2} & w_{1,2}^{1,3} & \cdots & w_{1,2}^{1,n} \\ w_{1,2}^{2,1} & w_{12}^{2,2} & w_{1,2}^{2,3} & \cdots & w_{1,2}^{2,n} \\ w_{1,2}^{3,1} & w_{12}^{3,2} & w_{1,2}^{3,3} & \cdots & w_{1,2}^{3,n} \\ \vdots & \vdots & \vdots & \ddots & \\ w_{i,j}^{m,1} & w_{i,j}^{m,2} & w_{i,j}^{m,3} & \cdots & w_{i,j}^{m,n} \end{bmatrix}$$

$$d_{i,j}^{m} = \int_{t_{i,j}^{h,A_0}}^{t_{i,j}^{h,A_0}+\delta\tau} \frac{\left(P_{i,j}^{h}(t) - D_{i,j}^{h}(t)\right)^2}{\left(P_{i,j}^{h}(t)\right)^2} dt$$

5. Corrosion assessment - Localization

From output image x : Apply threshold to isolate pixels with large indication



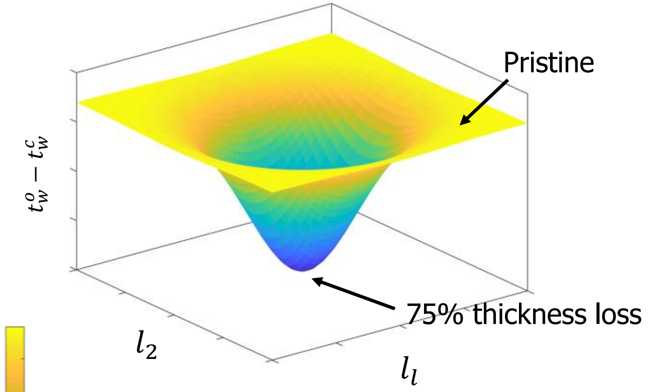
Coordinates stored in vector: $\{\boldsymbol{\epsilon}_{1,c}\}$

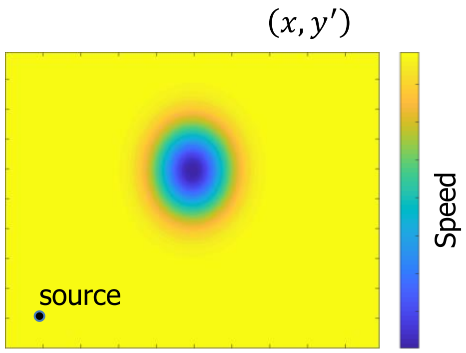
5. Corrosion assessment - Tomography

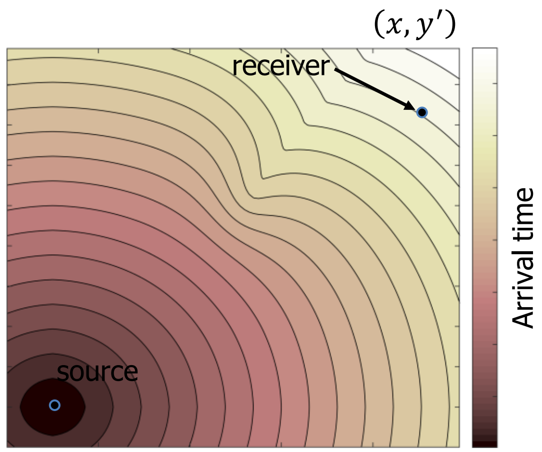
<u>2-dimensional acoustic modeling:</u>

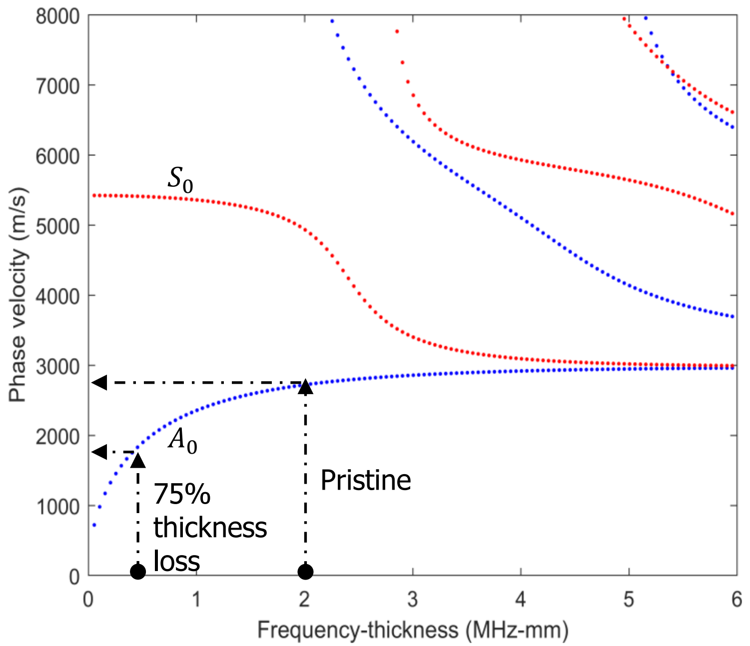
- Gaussian shaped corrosion $g = (l_1,\ l_2,\ t_w^c)$
- Initiate a circular wavefront
- Estimate arrival time at each node corresponding to actual sensor locations

Ex: Assumed Speed (Corrosion) profile









- Parametrizing corrosion dimensions
- Shift around the areas of interest r

$$g = (l_1,\ l_2,\ t_w^c, r)$$

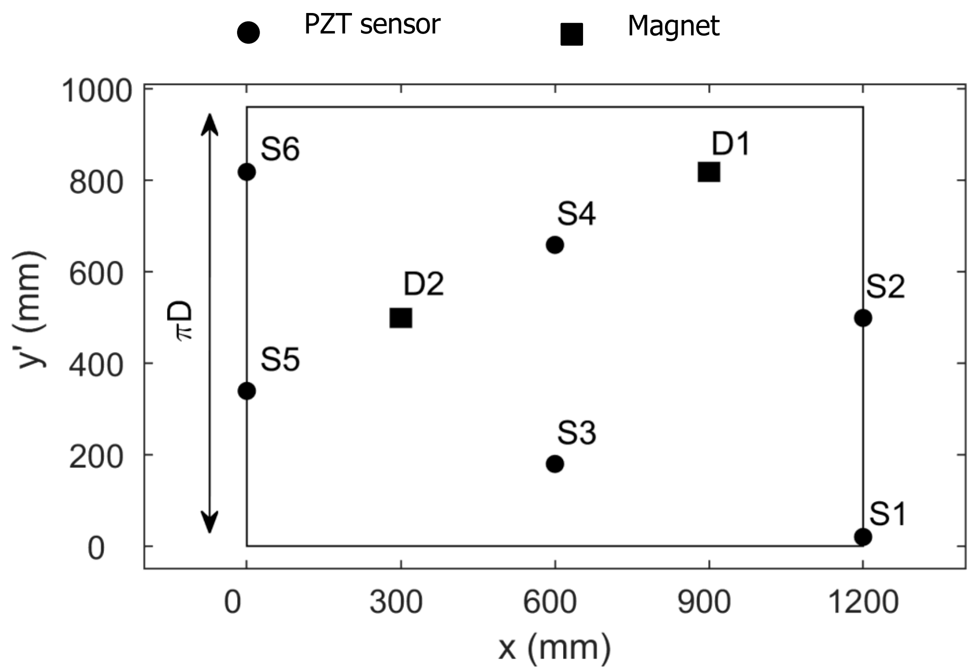
<u>Vector:</u> $\bar{\delta} t^{h,g}_{i-j,c} = t^{h}_{i-j,0} - t^{h,g}_{i-j,c}$

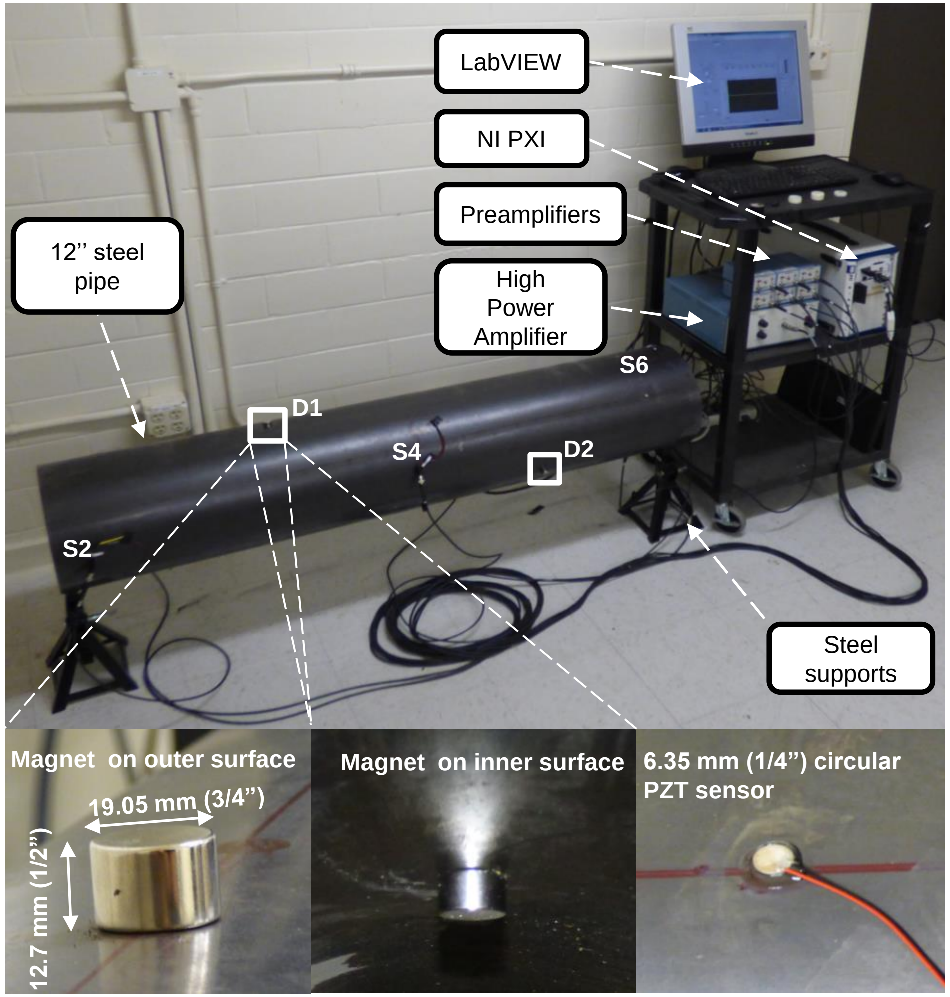
Pristine Current

6. Results

Sensor layout

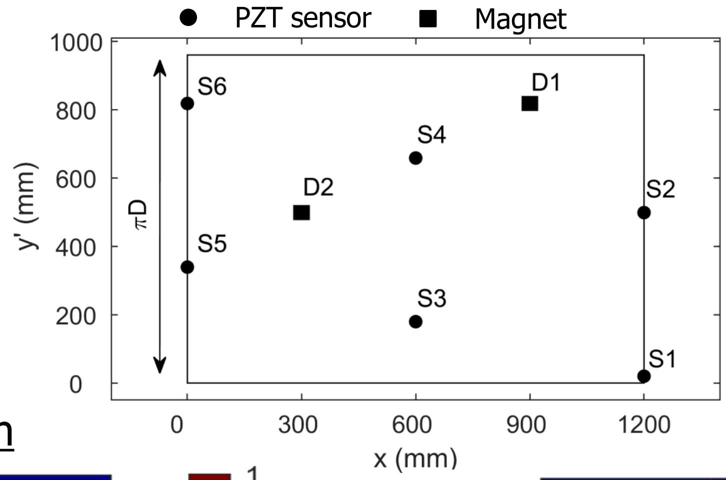
- 9 helical orders considered



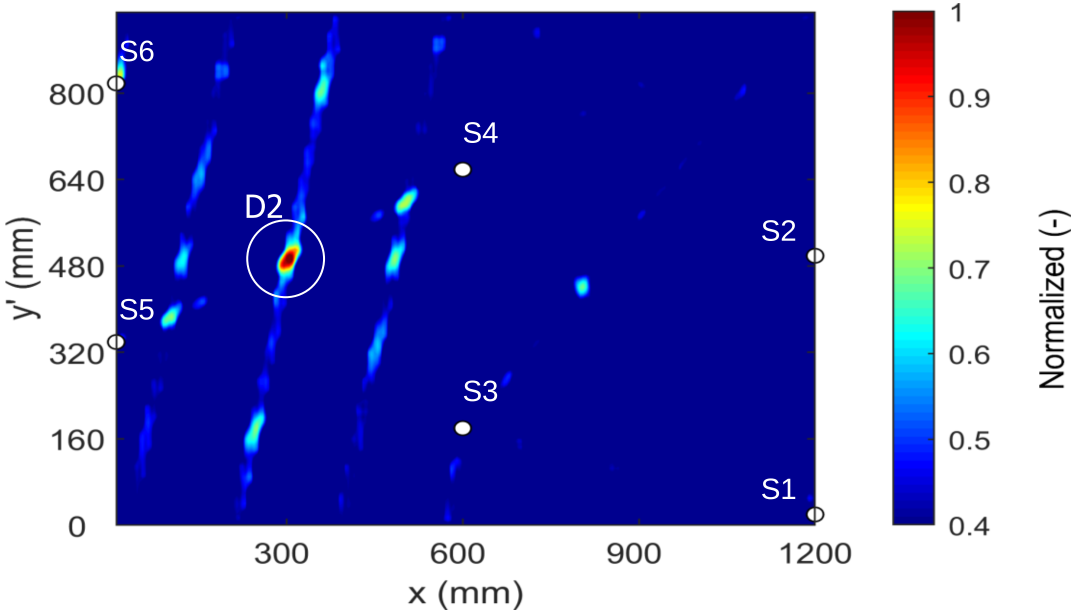


6. Results – Experiment #1

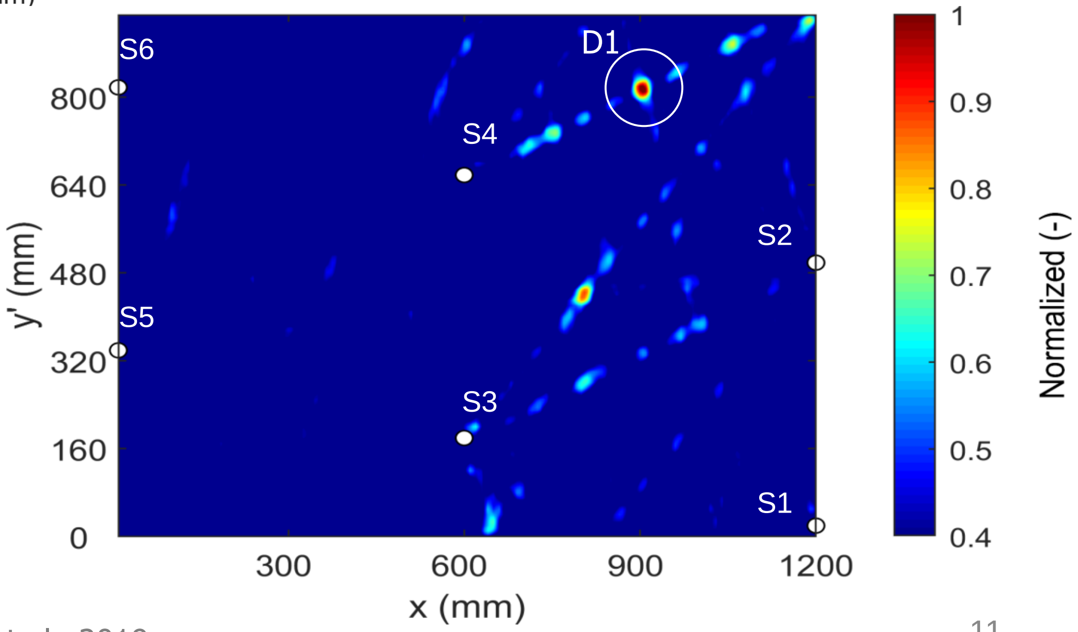
Magnet localizations



Artifacts 30% smaller than D2 indication



Artifacts 12% smaller than D1 indication

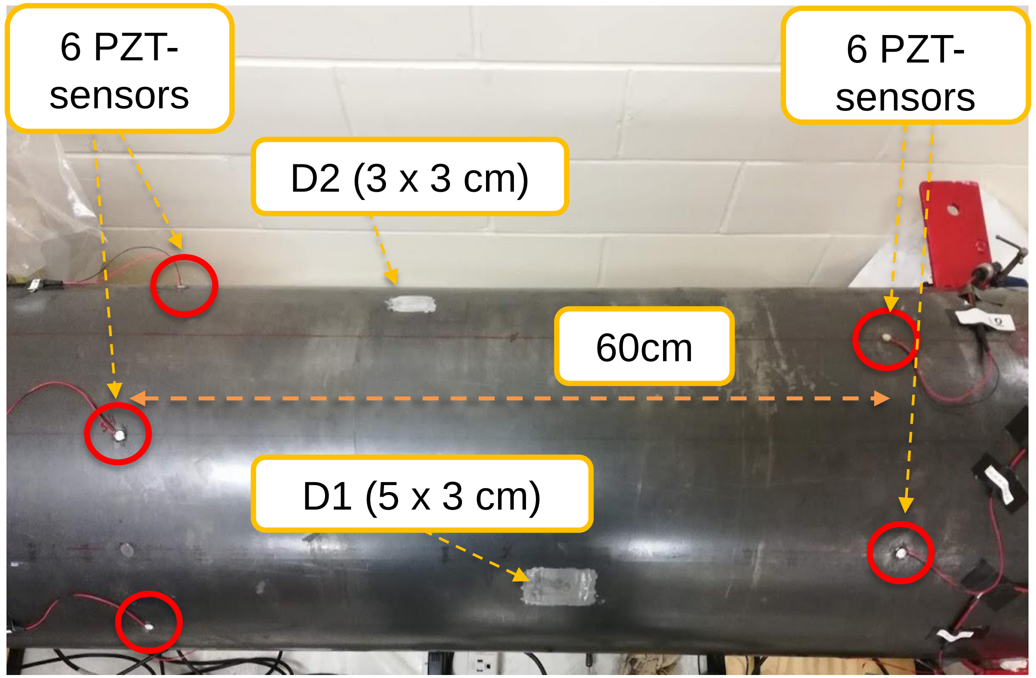


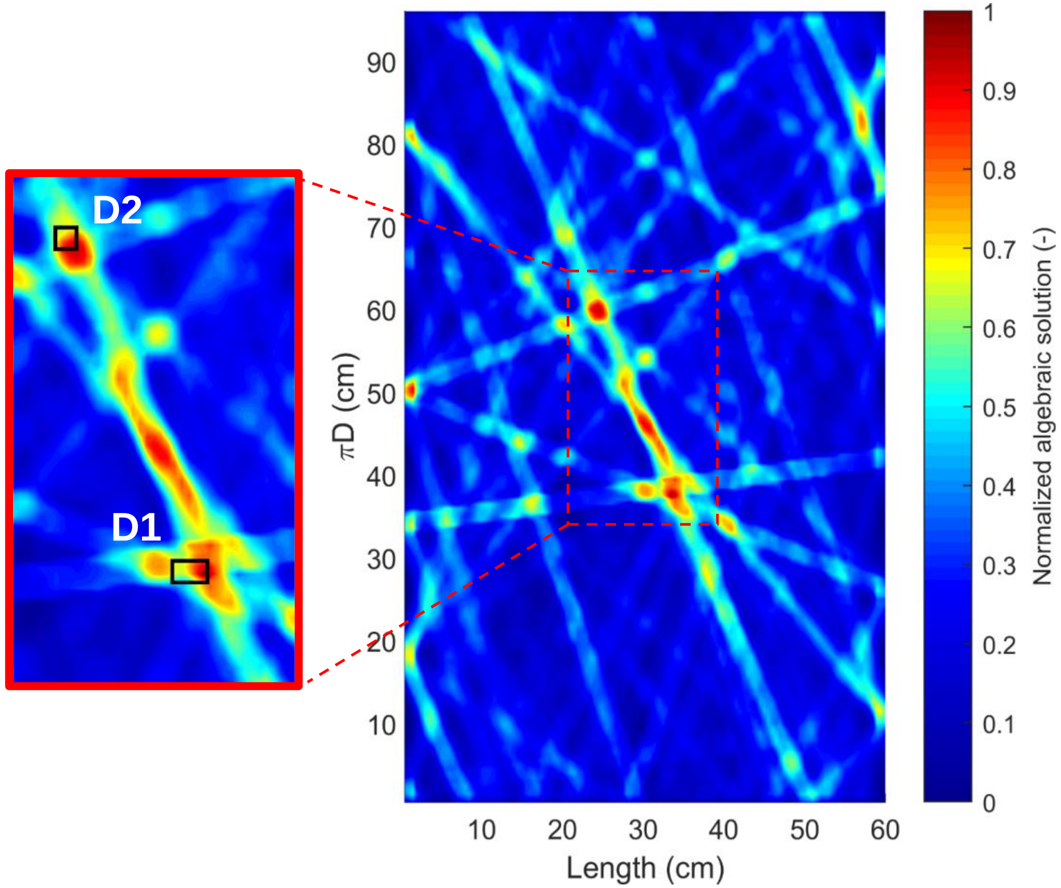
(1) Livadiotis et al., 2019

6. Results – Experiment #2

Localize multiple damages (D1 & D2) simultaneously

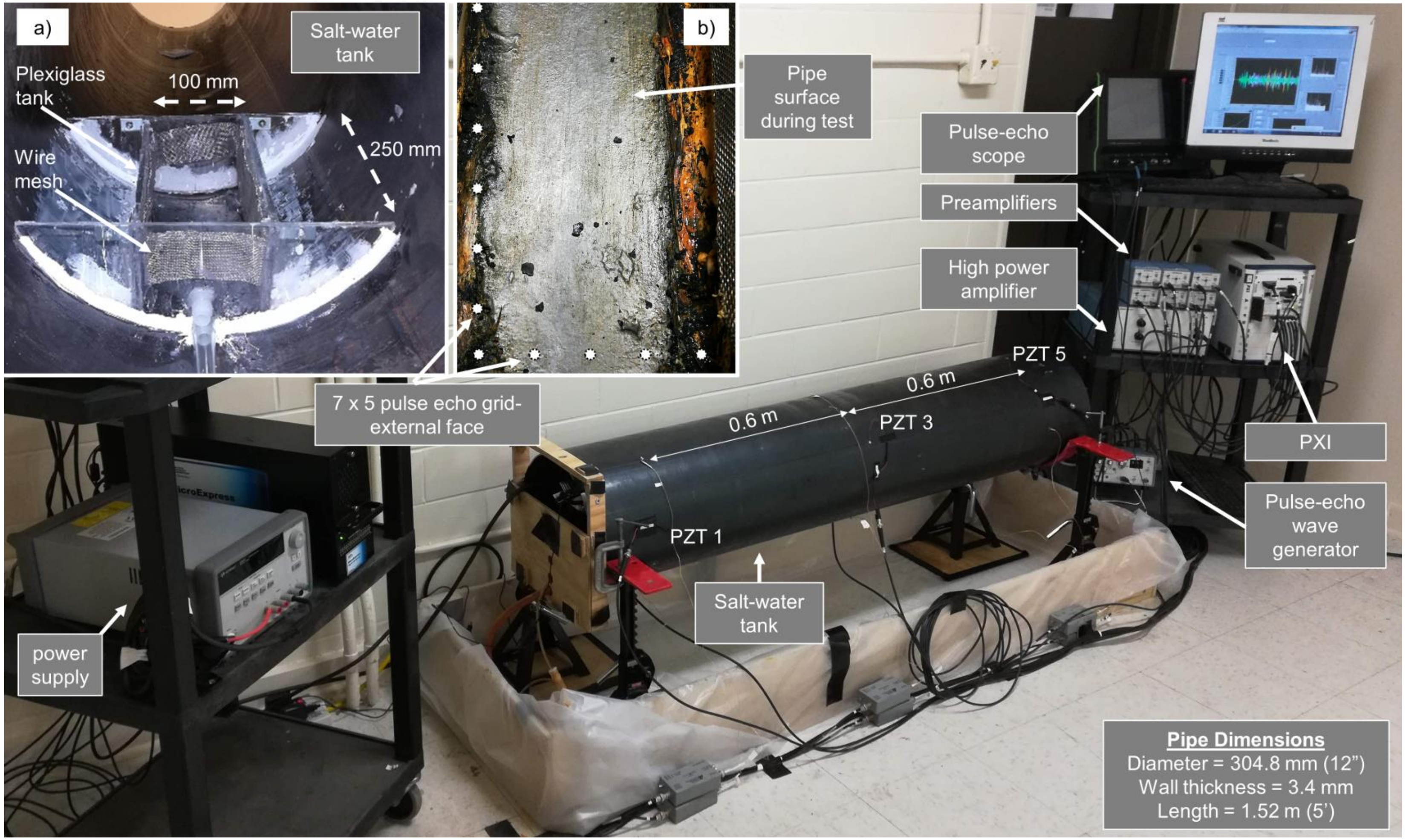
- Machined for 30% thickness removal

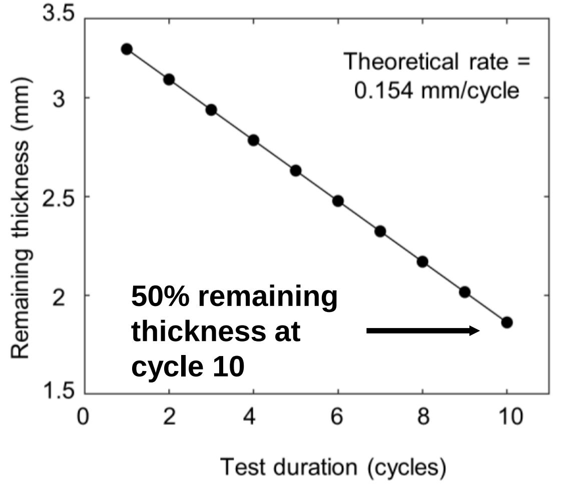


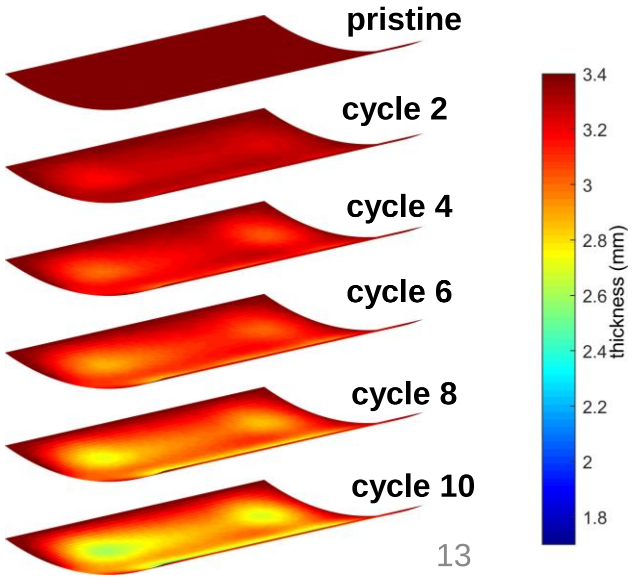


6. Results – Experiment #3

<u>Accelerated corrosion setup</u>



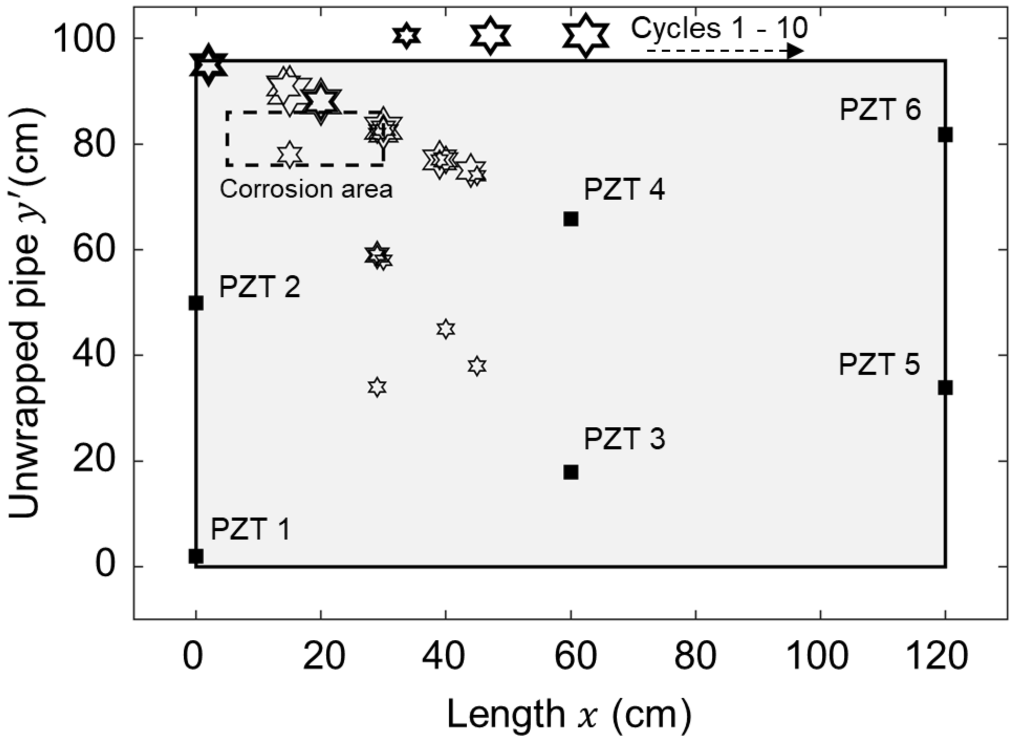




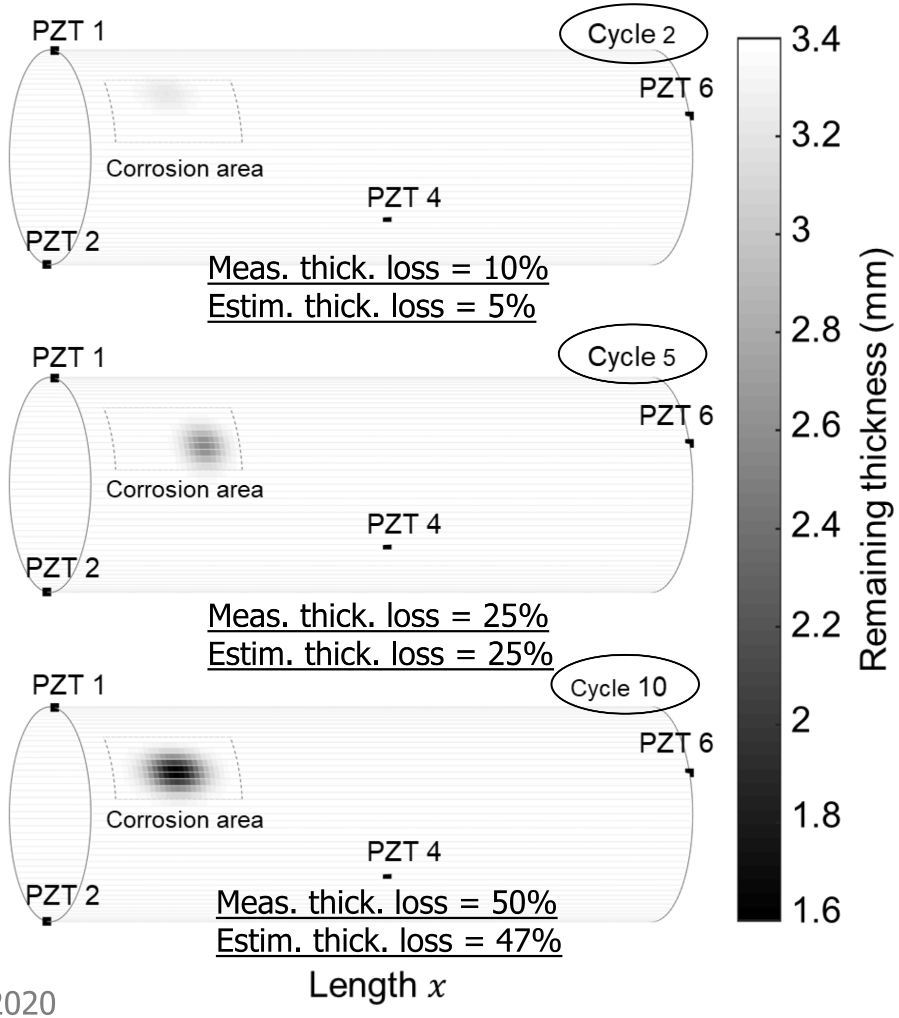
6. Results – Experiment #3

Experimental results

Corrosion localization for cycles 1-10



Tomographic results



Livadiotis et al., 2020

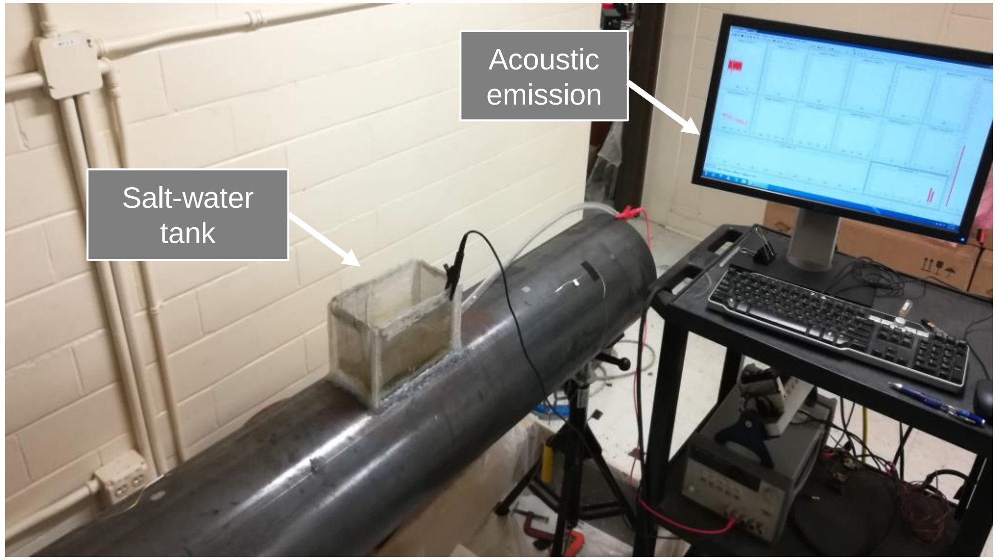
7. Acoustic emission (AE)

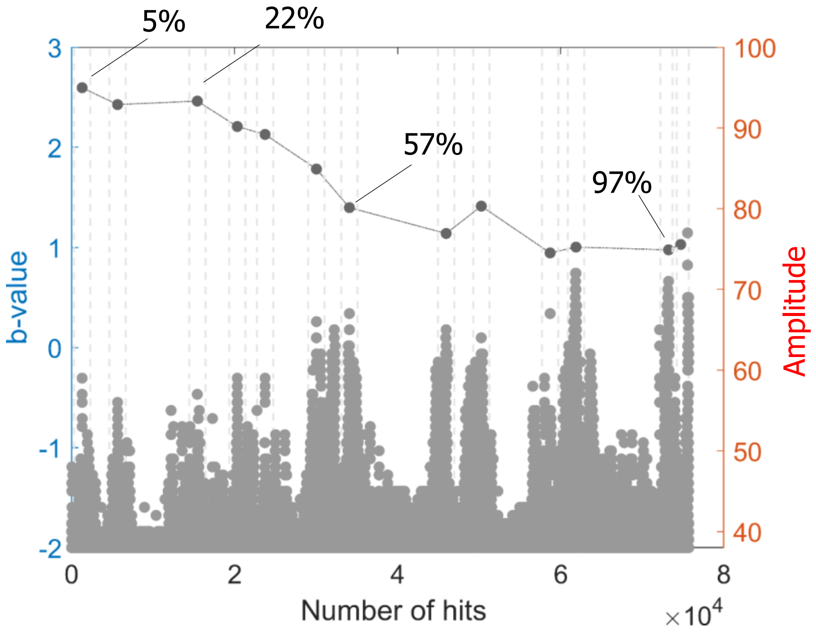
Employ passive method - Acoustic emission

- Correlate AE activity with the state of corrosion
- Use of the b-value analysis

Passive mode

Accelerated corrosion test #2





Summary

In this work

- Helical guided waves employed for corrosion assessment in steel pipes
  - Less sensing units required
  - Ability to perform qualitative and quantitative assessment simultaneously
- A 2-step localization – tomography approach was developed
- Approach was verified by:
  - Experimental tests simulating corrosion in various ways:
    - Magnets
    - Machining the surface
    - Accelerated corrosion
- Currently working on HGW-based AE techniques for corrosion assessment

Funding agencies

DEPARTMENT OF TRANSPORTATION
UNITED STATES OF AMERICA

PHMSA
Pipeline and Hazardous Materials Safety Administration

THANK YOU

Questions ?