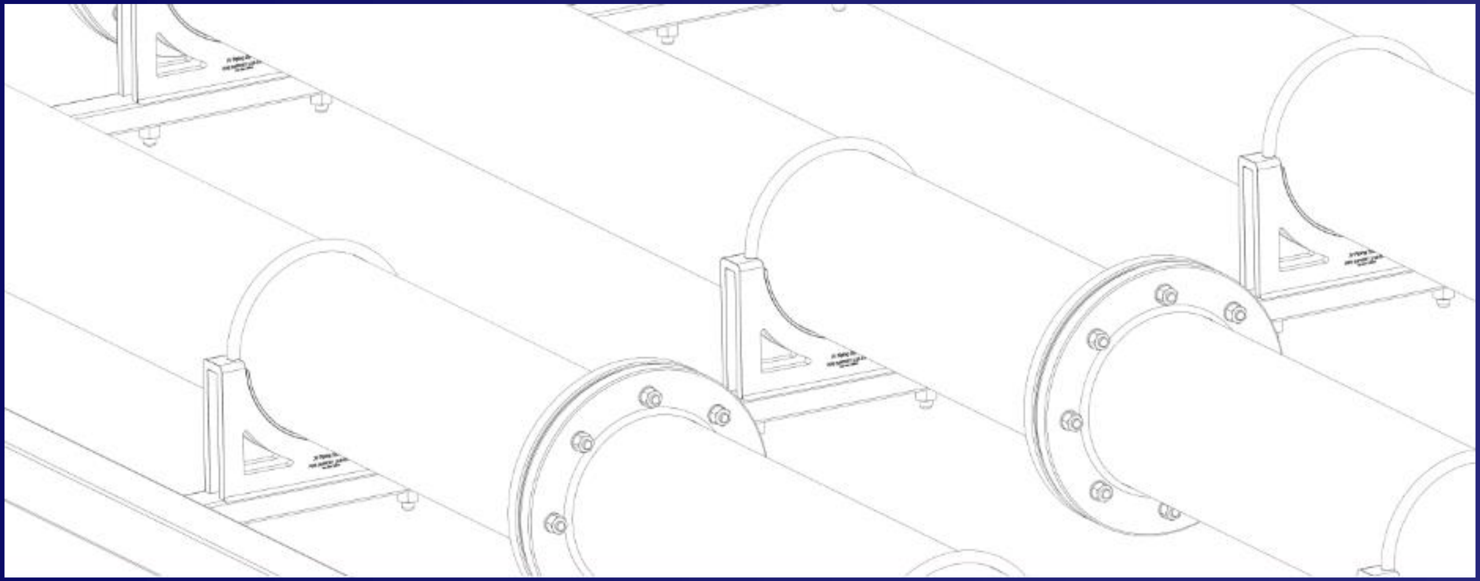
BINDT Telford

Guided Wave Testing and Monitoring Over Long and Short Ranges



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6 September 2017

Outline

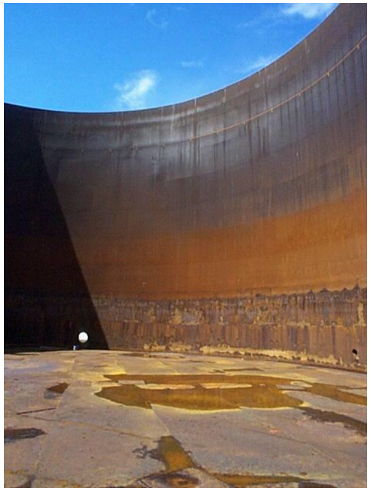
- Background
- Guided Wave Testing (GWT) Concepts
- Wave Propagation
- Tools for predicting and measuring guided waves
- Interaction of GW in plates and pipes
- Practical implementation
- Pipe testing and Monitoring
- Quantitative Short Range Scanning development
- Conclusions

GWT Background

- GWT research at Imperial College, London from 1980’s. Application to plates and pipes
- Commercial application from late1990’s and ongoing specialised development and advancement in guided wave testing for industrial inspection since.
- On-going Research at Imperial College, other Universities and research groups globally. Mostly for long range screening.

Imperial College NDT Group, 1991?

Can Guided waves be useful for NDT?

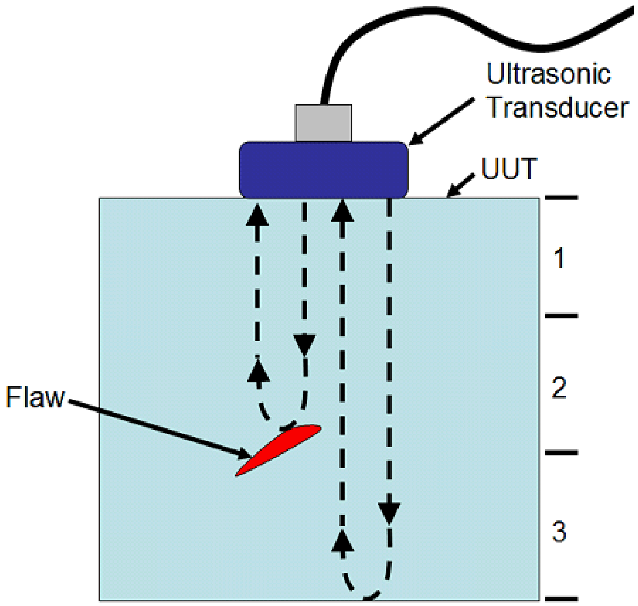


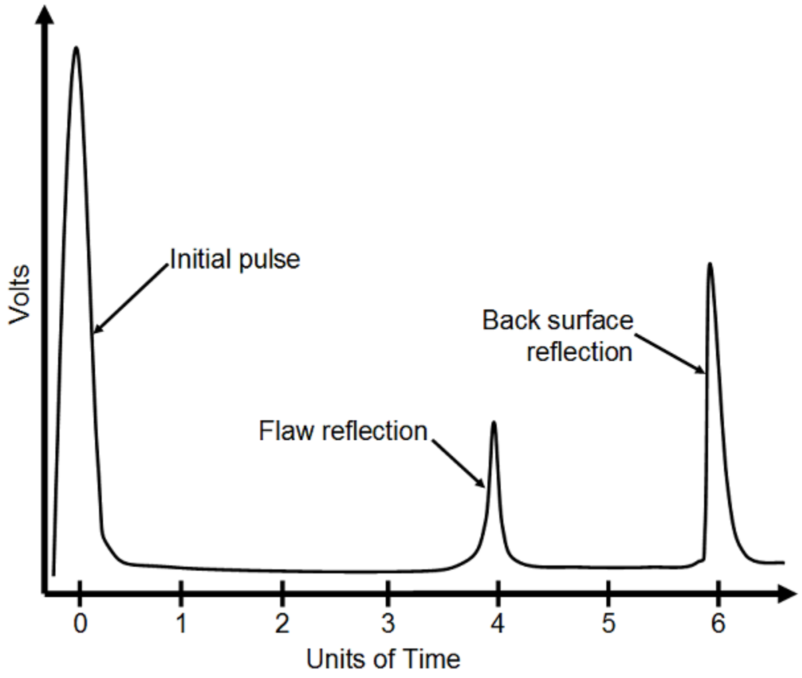
Example Plants where guided waves…

Need to find corrosion…..

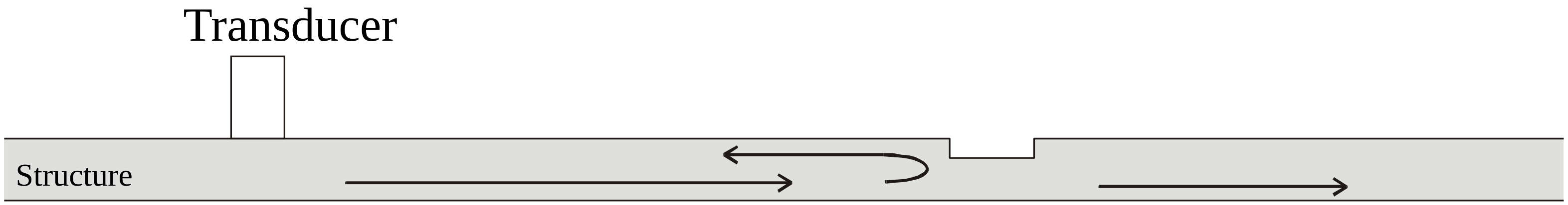
Ultrasonic Testing (UT) Concept

Pulse-echo test

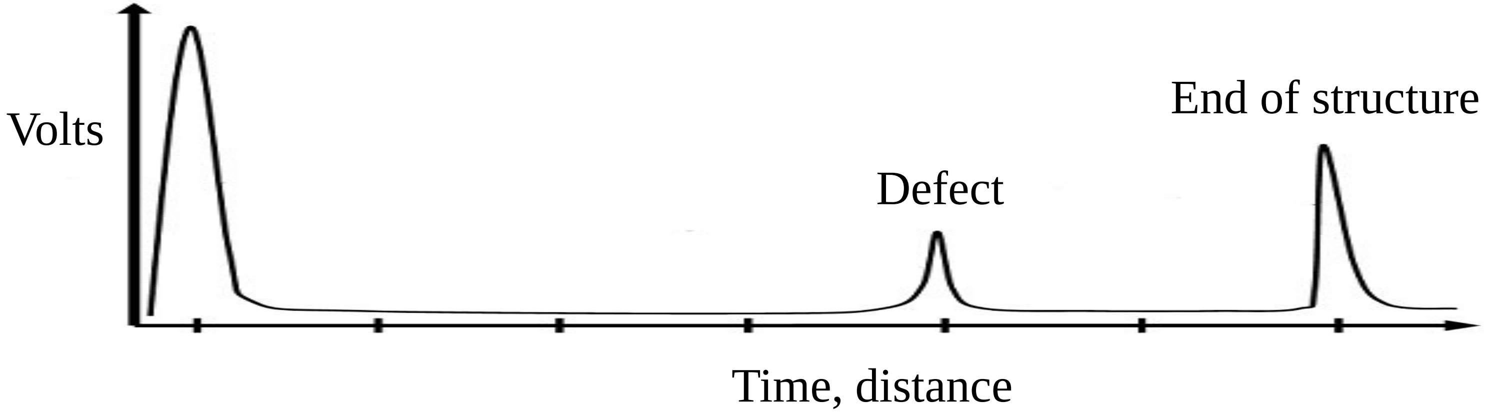




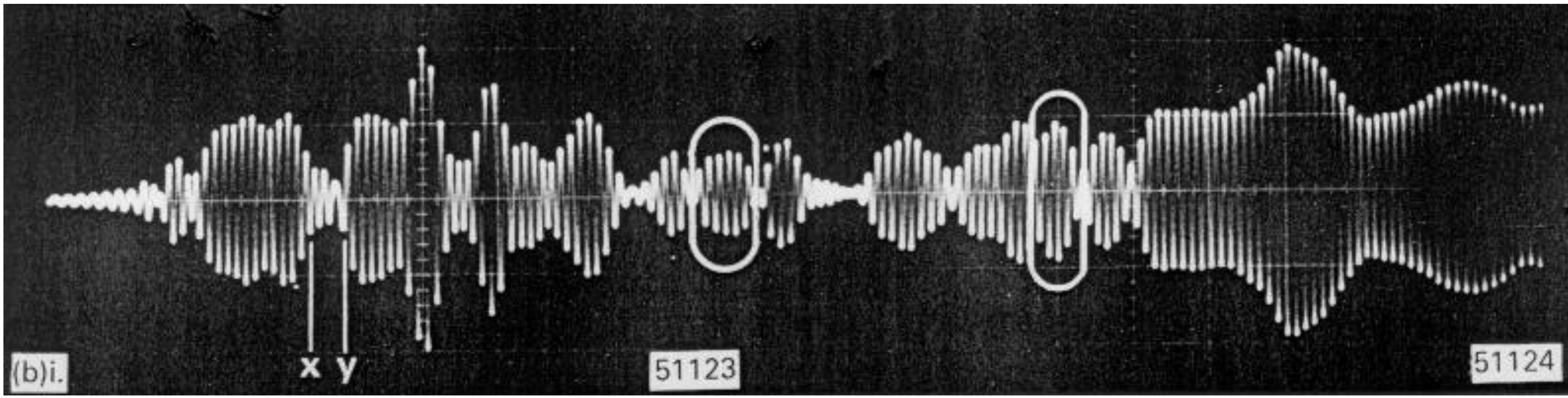
GWT Screening Concept (LRUT)



- If the guided wave encounters a defect then part of the signal is reflected
- A single measurement inspects all the material in a long length of the structure



What happens if we just try......

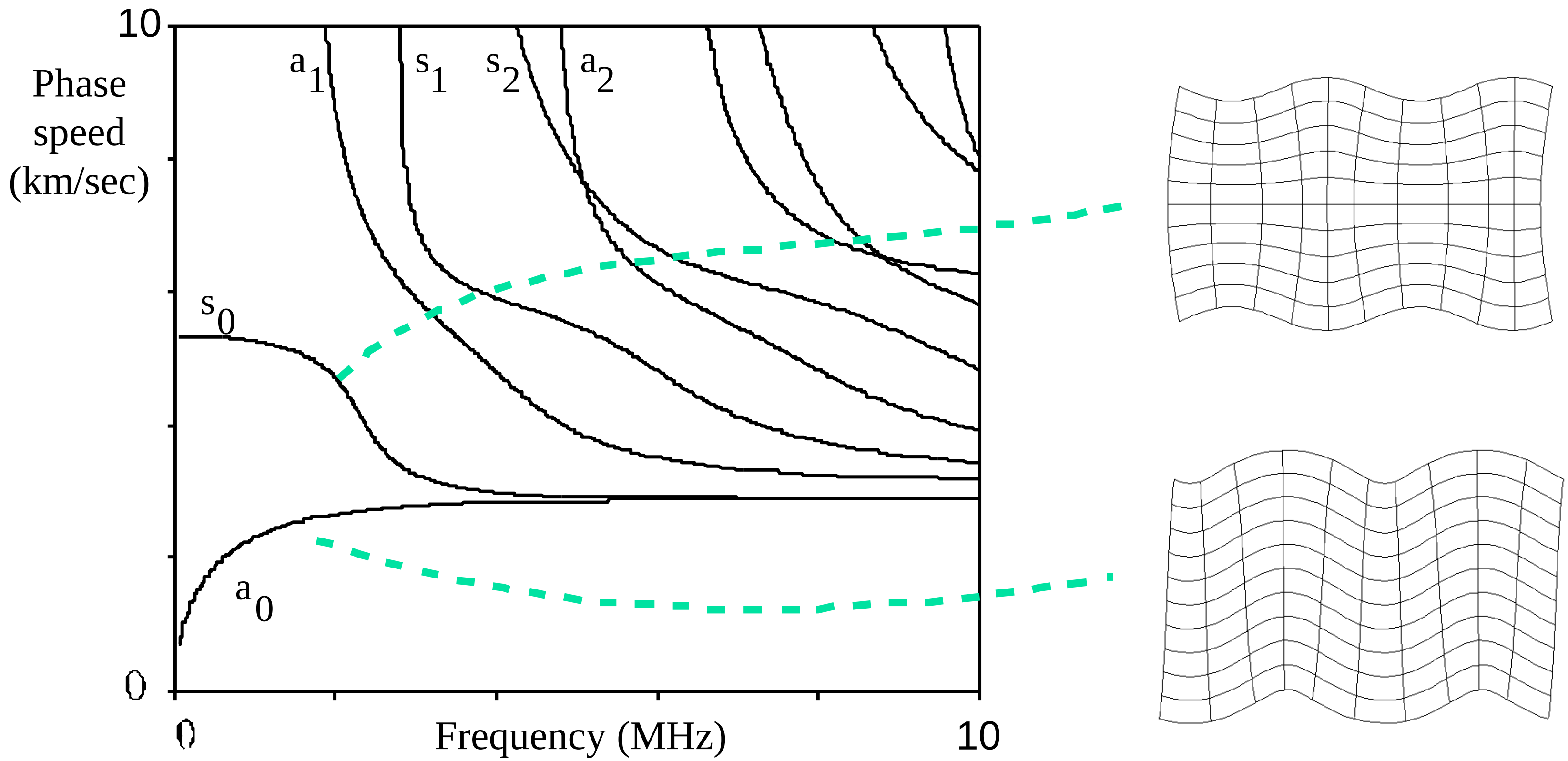


Problems:

- Multiple modes
- Dispersion
- Sensitivity to defects varies with modes

Guided wave dispersion curves

"Dispersion curves" for a 1mm thick steel plate

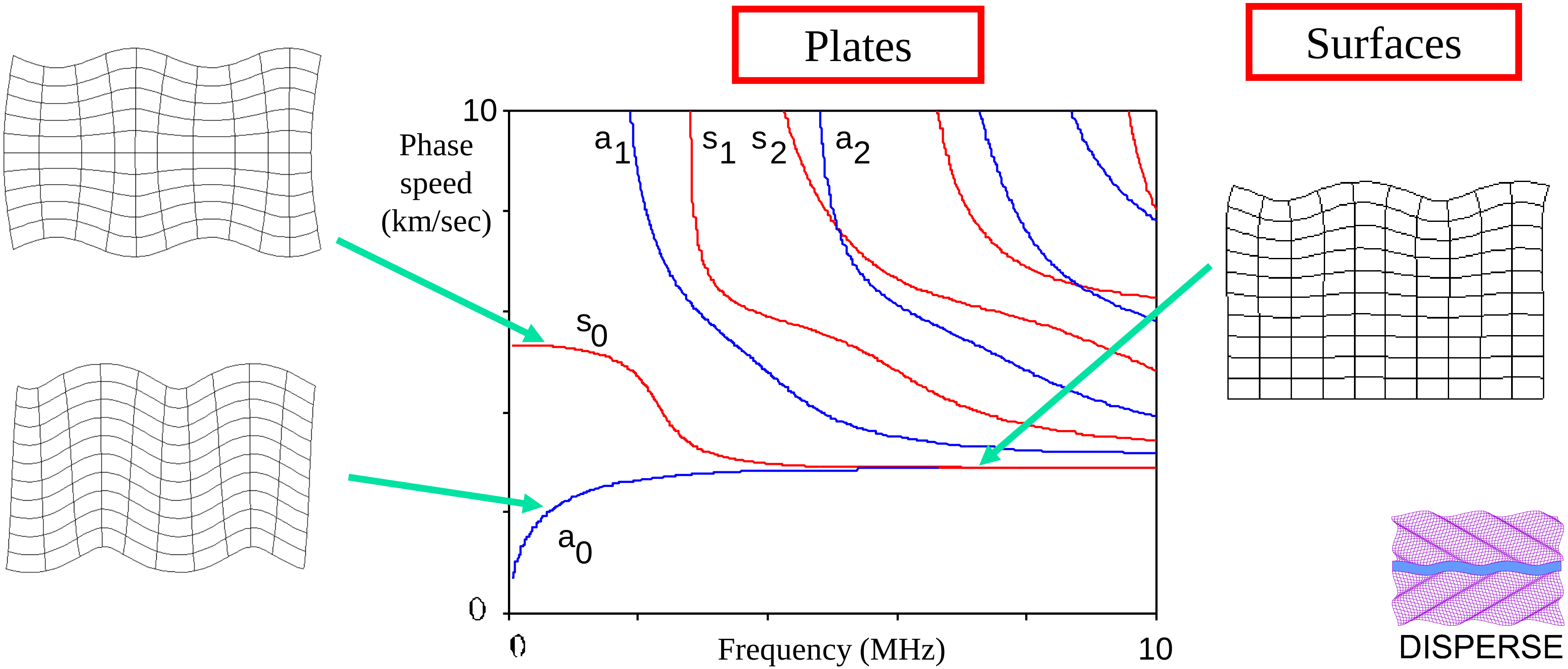


L Rayleigh (1885); H Lamb (1917)

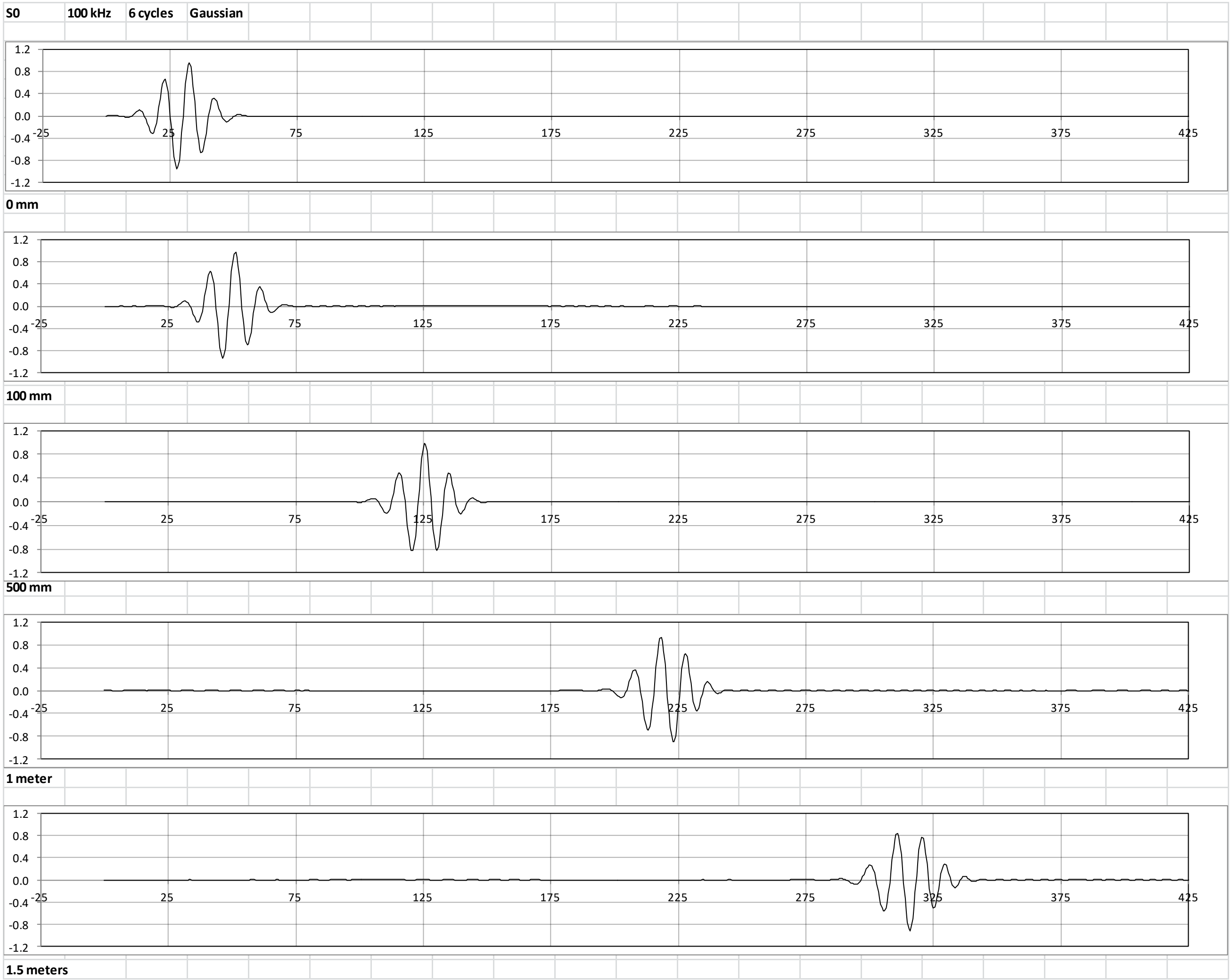
Development of the waveguide model

DISPERSE

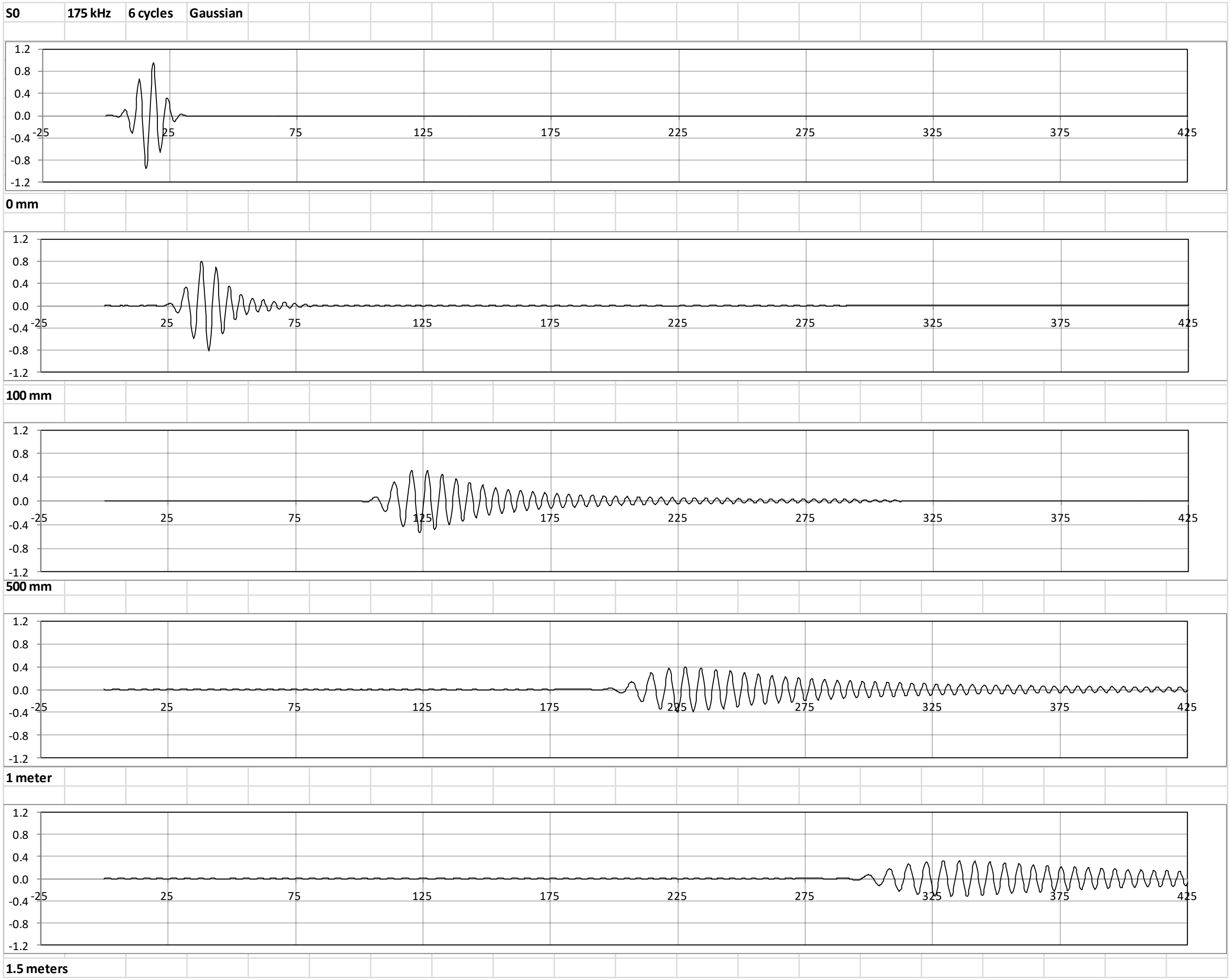
Developments packaged in the modelling tool "DISPERSE"



S0 at 100kHz (10mm Steel plate)



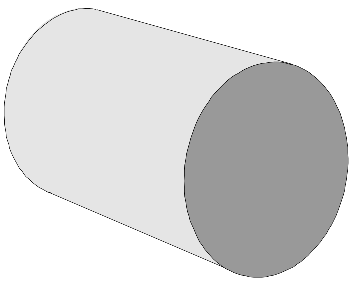
S0 at 175kHz (10mm Steel plate)



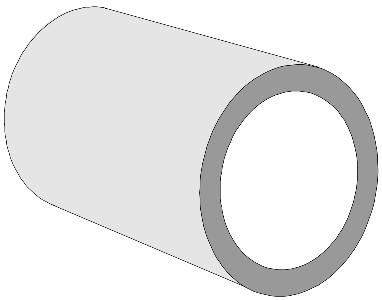
......and also:

Solids, fluids, anisotropic....

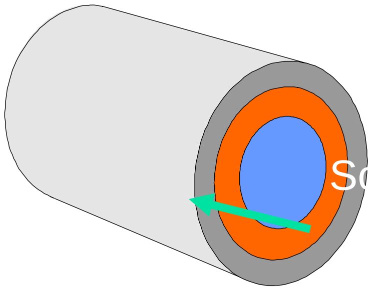
Bars



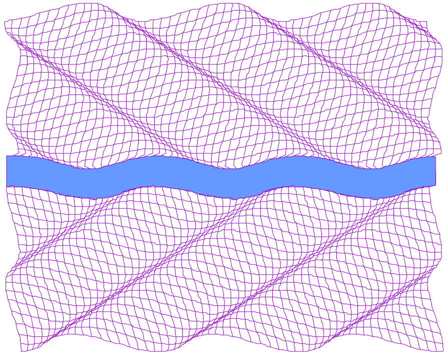
Pipes



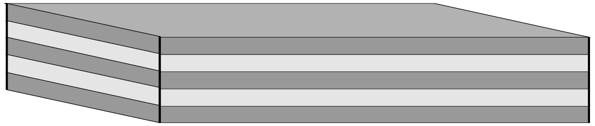
Multiple layers

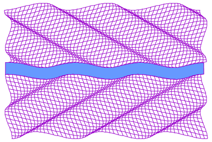


Embedded or immersed



Composites



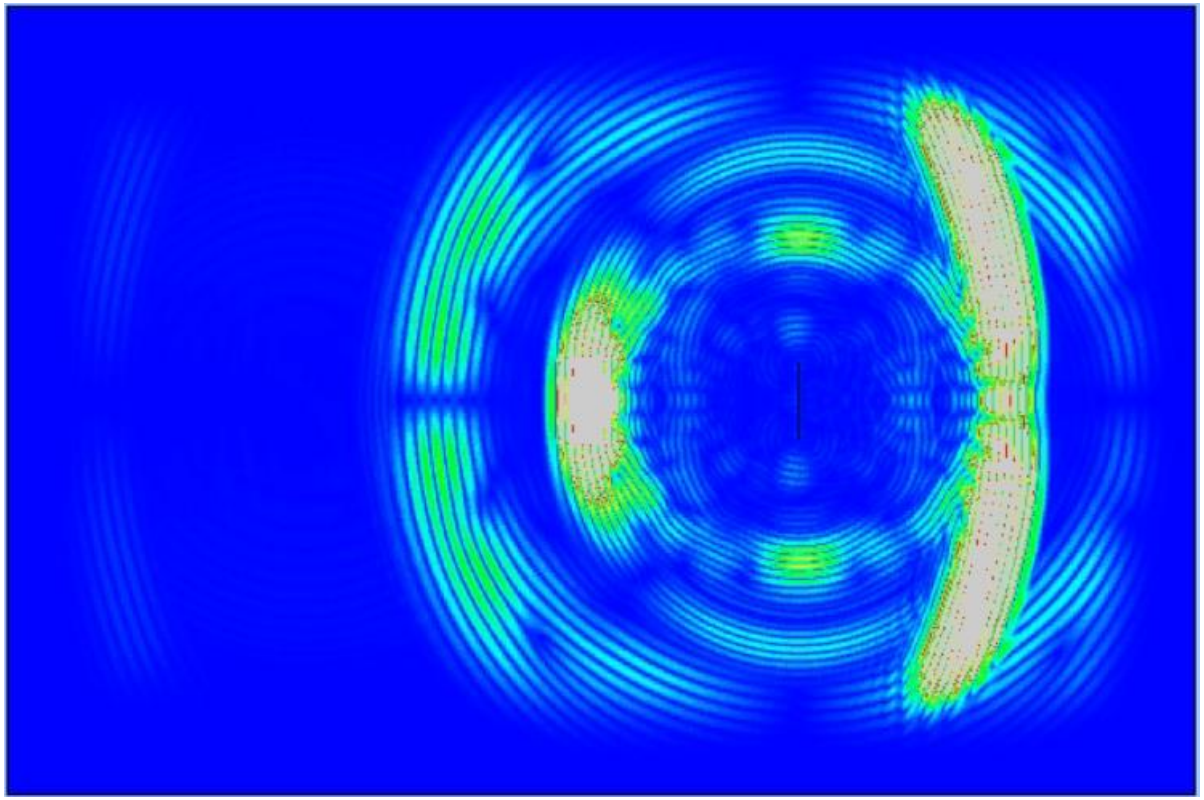


DISPERSE

Development of Finite Element Modelling

Tools

Scattering of guided waves from a crack

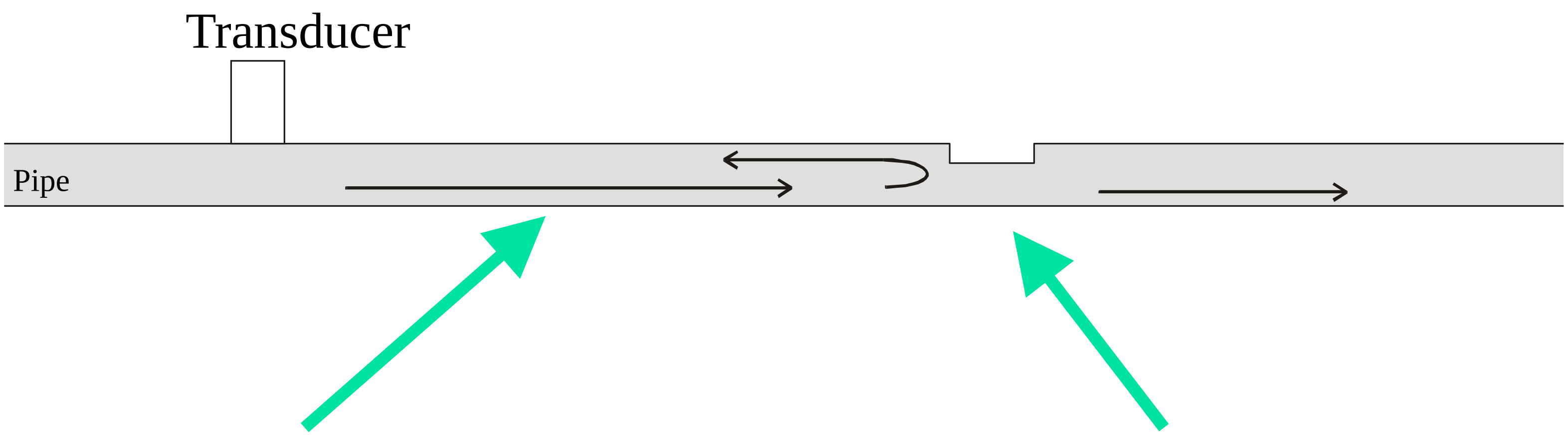


Rajagopal, Lowe. J Acoust Soc Am, 122, 2007.
Rajagopal, Lowe. J Acoust Soc Am, 124, 2008.

Drozdz, Moreau, Castaings, Lowe, Cawley. Rev Prog QNDE, 25, 2006.
Drozdz, Skelton, Craster, Lowe. Rev Prog QNDE, 26, 2007.

Expertise, knowhow requirements...

Need to do a lot of R&D, including:



Need to understand the waves

Need to understand how they reflect from defects

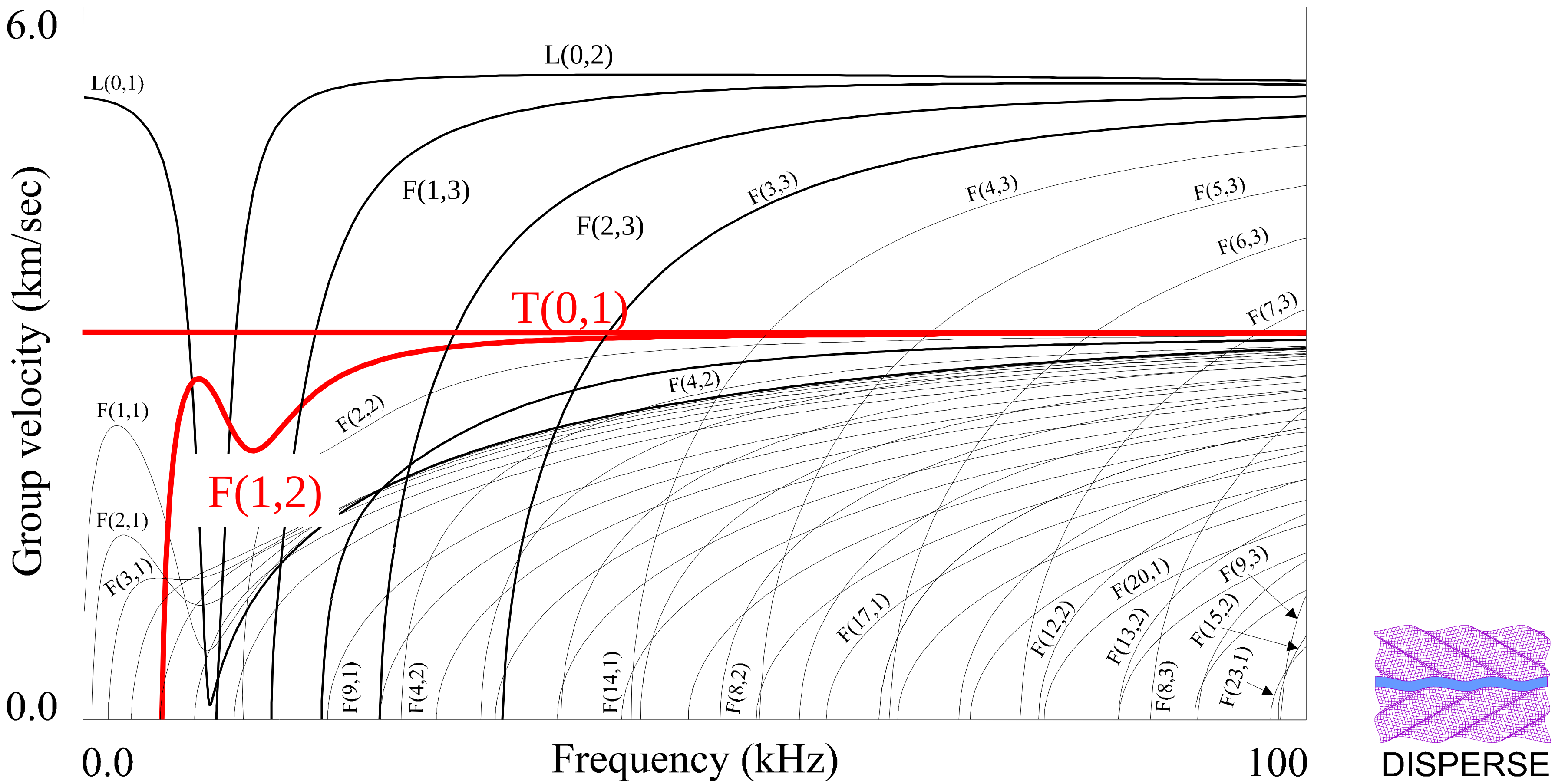
...then develop transducers, instrumentation, controlling software, signal processing, interpretation, operator training, formal procedures..... NDT inspector training and qualification

Strategy for development of Guided Wave Testing

- Select a guided wave mode that is sensitive to defects of interest
- Select frequency and signal shape to control dispersion
- Excite and receive specific mode(s)
- Control directionality

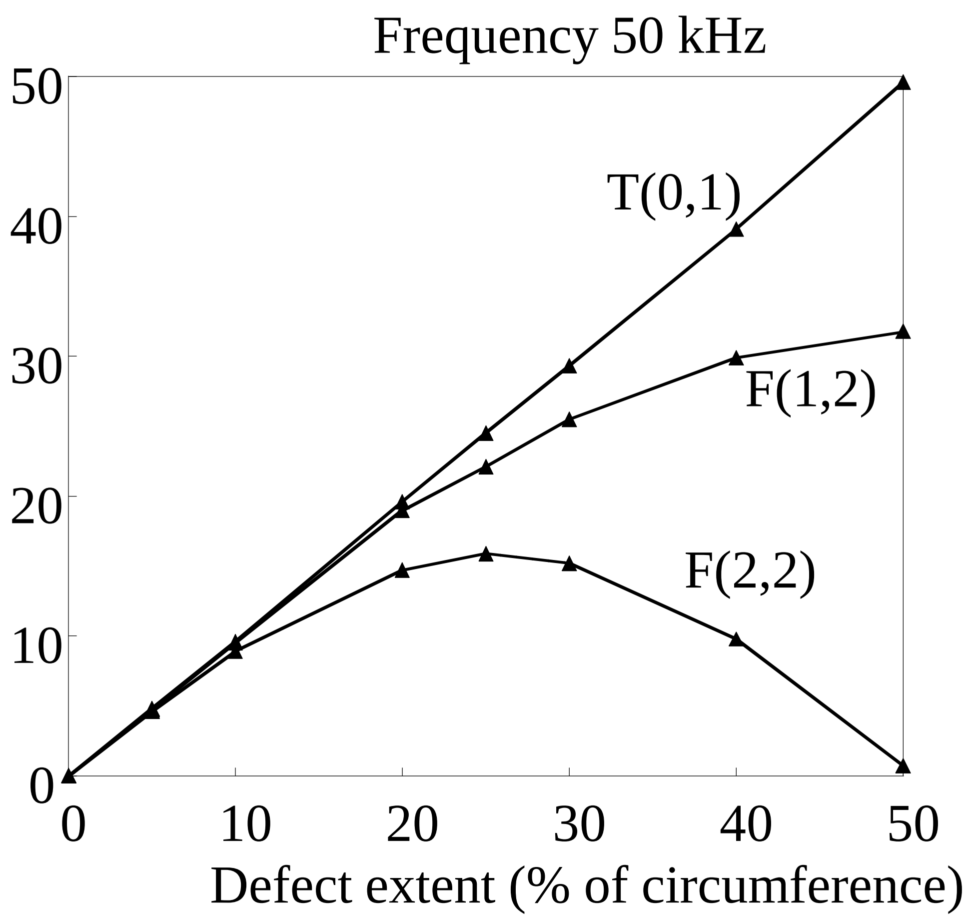
Guided waves for Sch 40 6” pipe

Dispersion Curves



Reflection coefficient versus circumferential length of defect

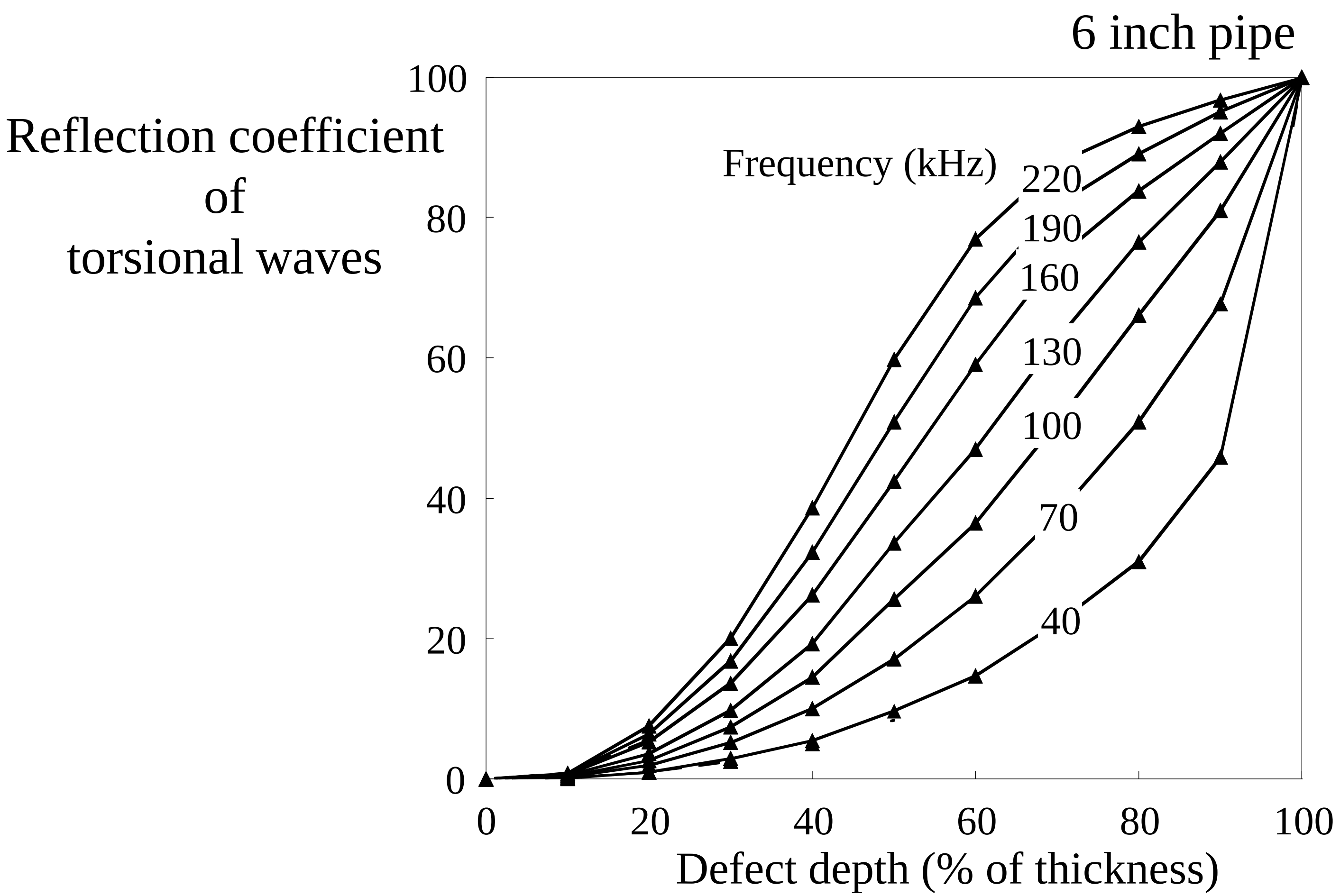
Reflection coefficient
of
torsional waves



Alleyne, Lowe, Cawley. ASME J Appl Mech, 65, 1998.
Lowe, Alleyne, Cawley. ASME J Appl Mech, 65, 1998.

Similar study done for extensional modes

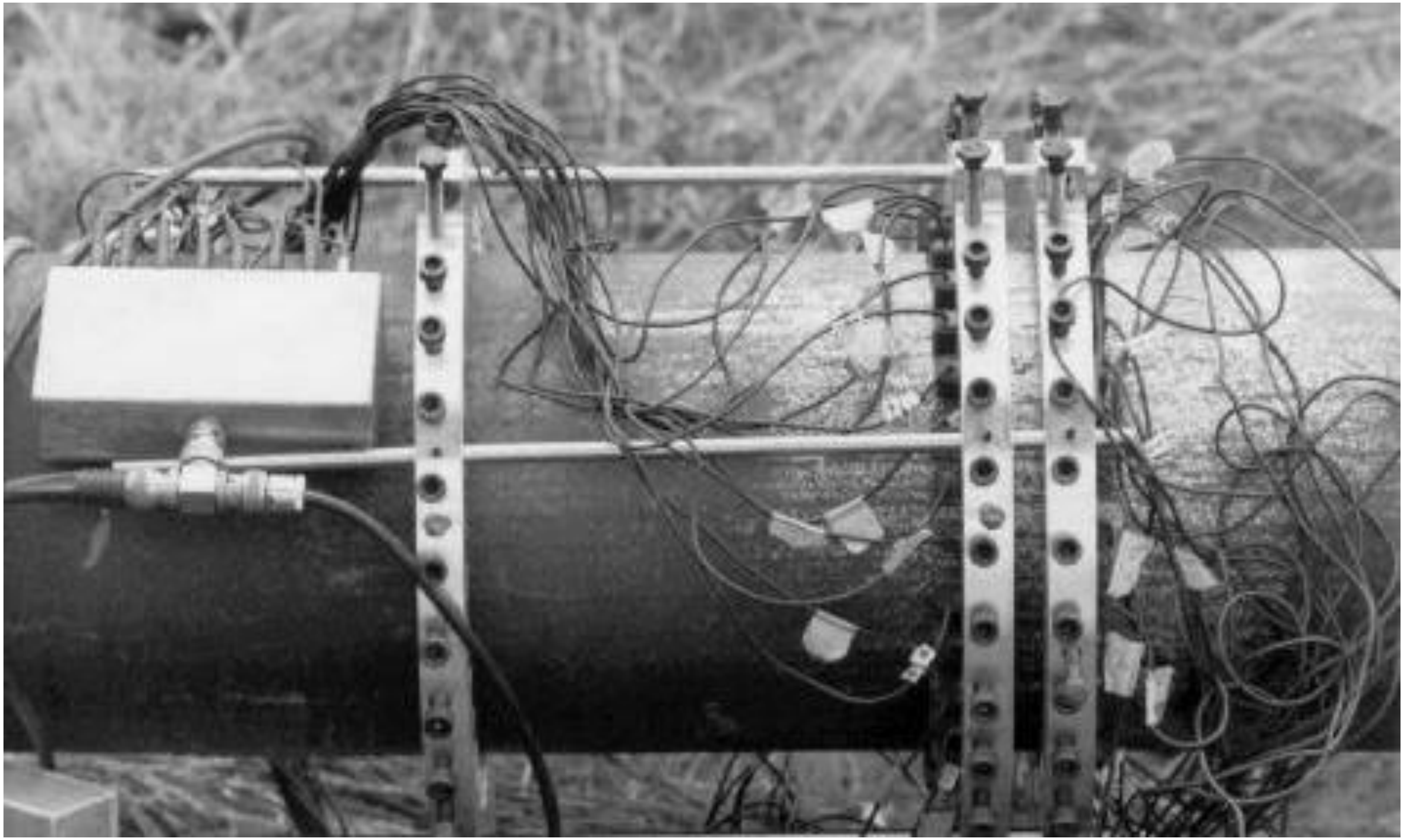
Reflection coefficient versus depth of defect



Alleyne, Pavlakovic, Lowe, Cawley. Insight, 43, 2001.

Similar study done for extensional modes

Early Research Transducers (early1990's)



Extensive Product Range (2015)

Guided Wave Transduction Systems

Wavemaker G4^{mini}

Wavemaker G4

HD: High Definition
HT: High Temperature

Transducer Rings

Inflatable Ring

HT Inflatable Ring

HT Solid Ring

Low Profile Ring

Solid Ring

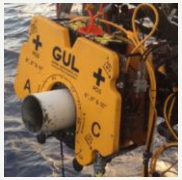
HD Solid Ring

HD Inflatable Ring

Claw Transducers

Lightweight Inflatable Ring

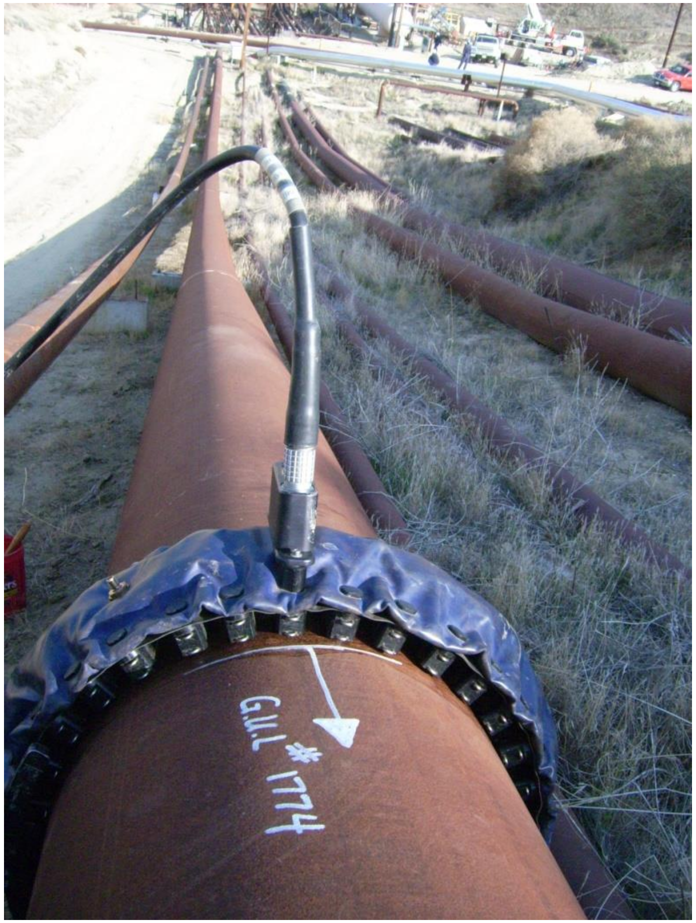
Permanently Installed (gPIMS)



Subsea Ring

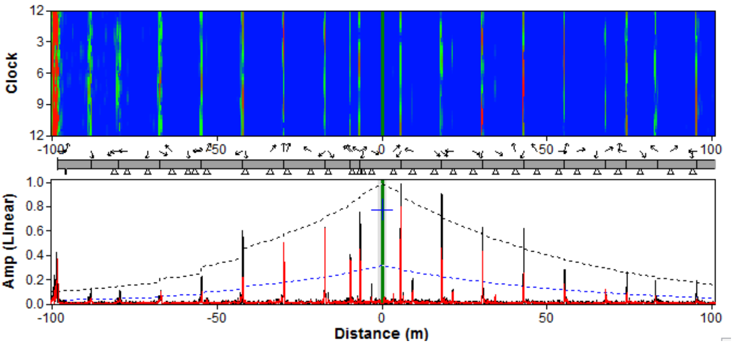
Rail Systems (G-Scan)

Long range pipe screening

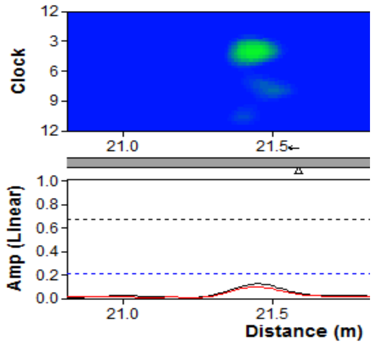


Why use Guided Waves

Rapid long range screening



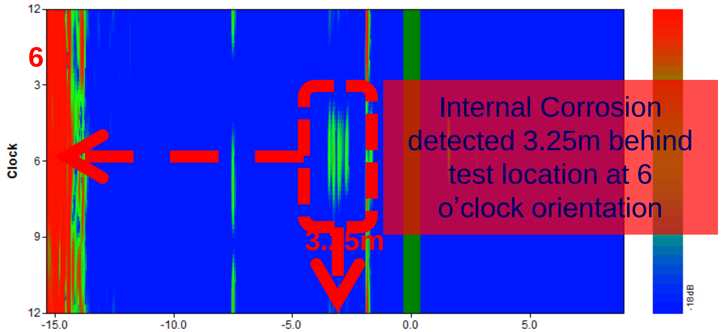
Screen inaccessible areas



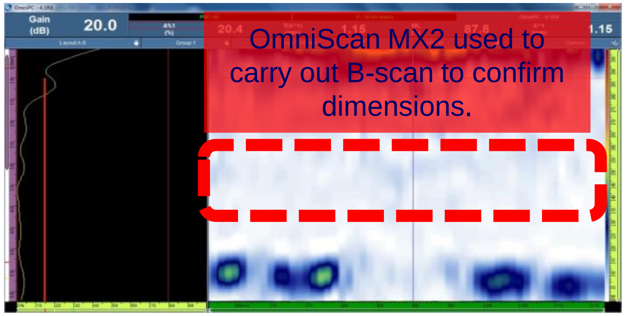
NPS 20” main gas gathering line

Why use Guided Waves

100% volumetric pipe coverage



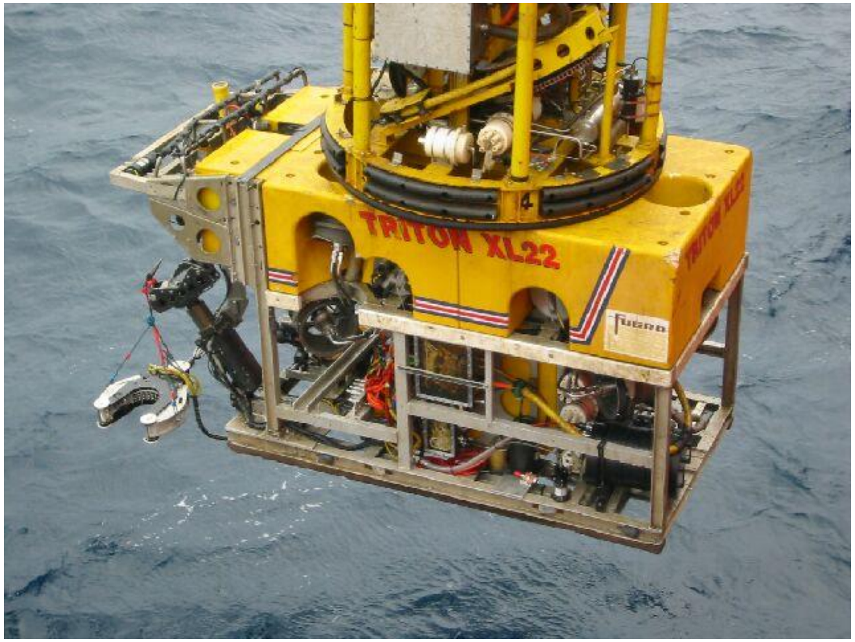
Accurately locate defects



NPS 6" Gas Line, North Africa

Testing offshore

Testing sub-sea



Guided Wave Testing Standards

- BSI – BS 9690-1:2011; BS 9690-2:2011
- ASTM – E2929-11
- ASME – Article 18
- NACE TG 410 – 2014
- IIW – Commission V – EN ISO (TC135/SC3)
- TUV certification: GUL GWT procedure certified under EN standard 14748

Calibration critical for procedures

- Challenge is to develop GWT procedures and work instructions using knowledge of the damage type that is the major threat
  - Equipment and certification requirements
  - SNR and access restrictions
  - Limitations
  - Accuracy range and confidence

- Calibration is critical

Guided Waves Calibration

- Equipment calibration
  - Manufacturer‘s calibration (electronic components)
  - Automatic self-test functions
- User calibration
  - Set-up of test parameters, e.g. ring size, transducer, test frequencies (mostly automated)
- Reference standard

test object = calibration test piece

  - Distance calibration
  - Comparison of the amplitude of indications with a reference

Guided Waves Calibration

Summary

- Calibration methods until now sufficient for screening, but demanding applications require a more precise approach
- Direct measurement of outgoing amplitude possible with absolute calibration method (or of reflection coefficients with attenuation known)
- Removes most problems of current calibration methods
- Works also with other features (not just welds), even if defective
- Ultimately this leads to improved false-call rate and therefore reliability

CUI and road crossing pipes

- Road crossings and insulated pipe inspected for CUI
- Inspections while pipes operational

CUI

- Insulated steam pipe-work at 340°C
- Pipes tested while operational

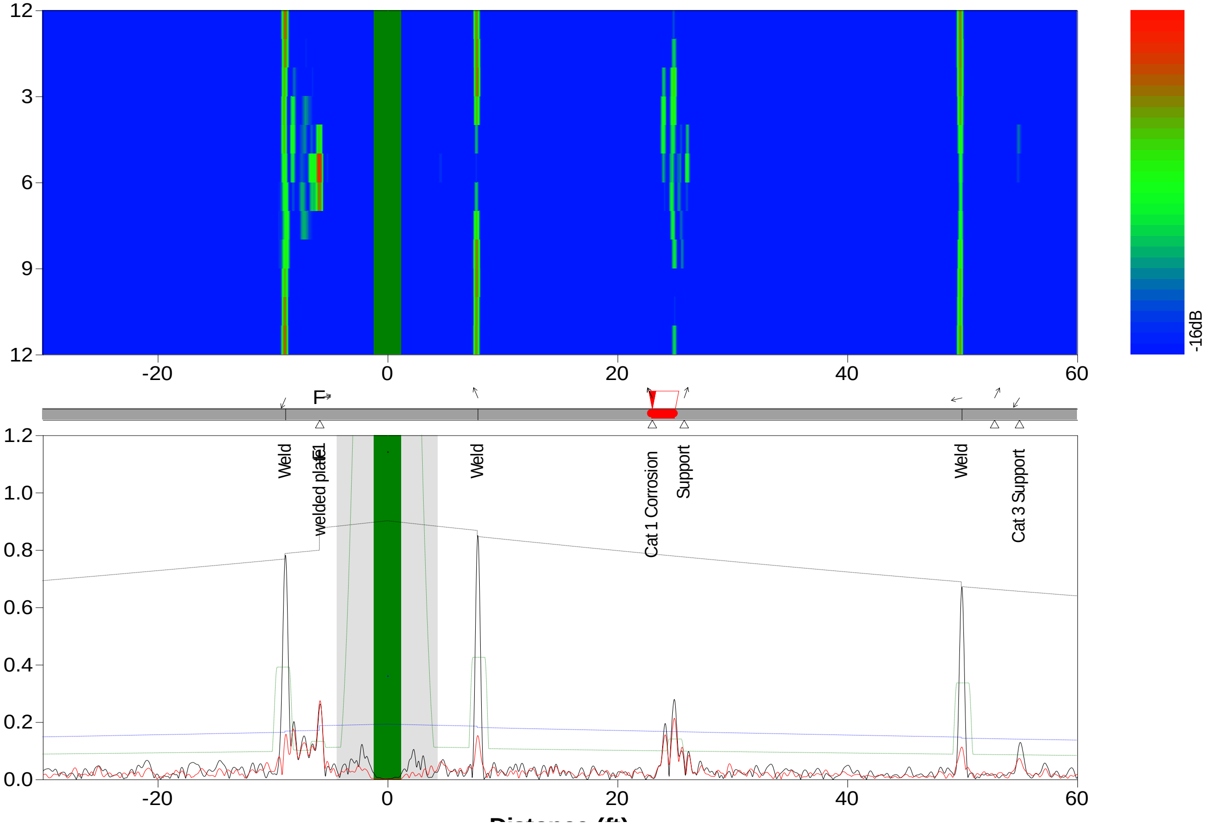
Corrosion Under Supports (CUPS)

Touch point corrosion detected using GWT. The CSC range can be less than a few per cent, therefore control of the GWT critical for success. More later

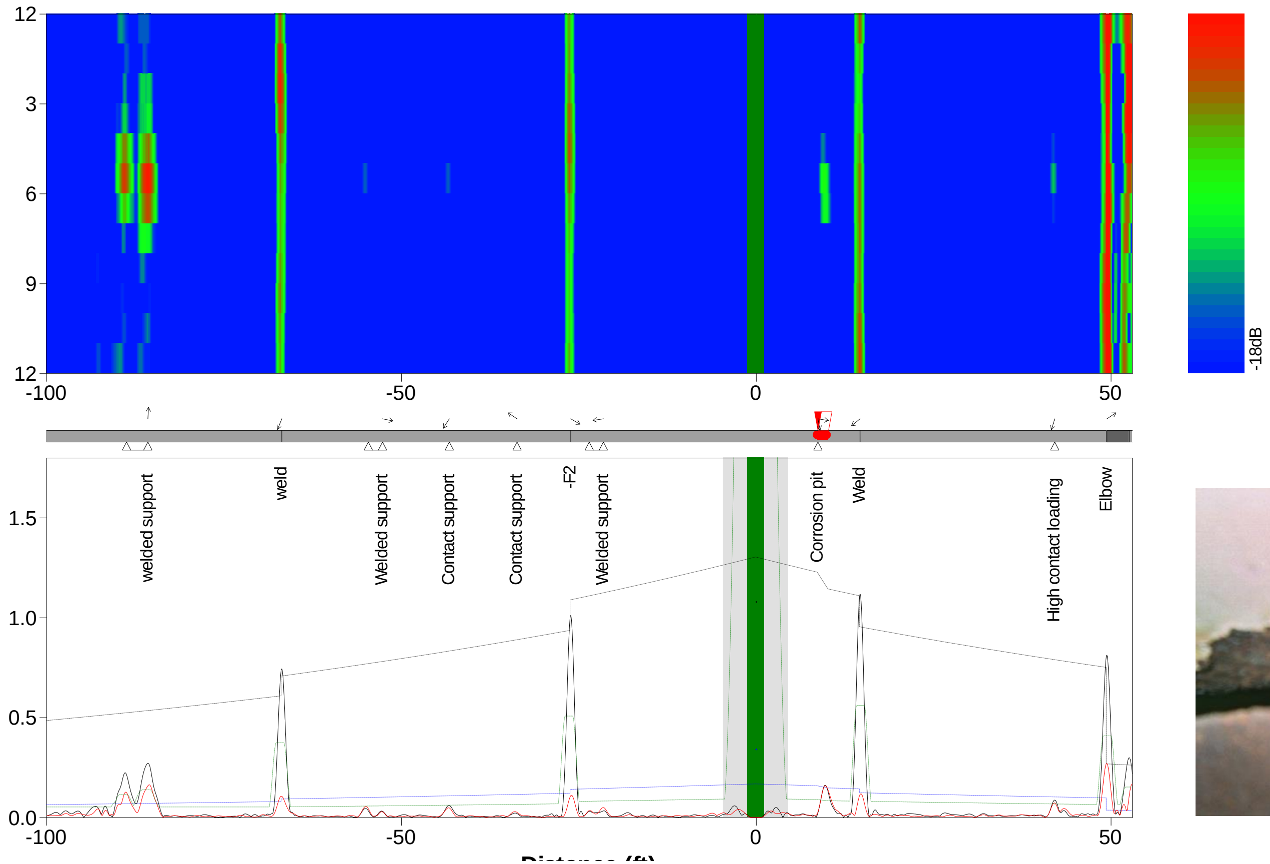
GWT strategy – Touch Point corrosion

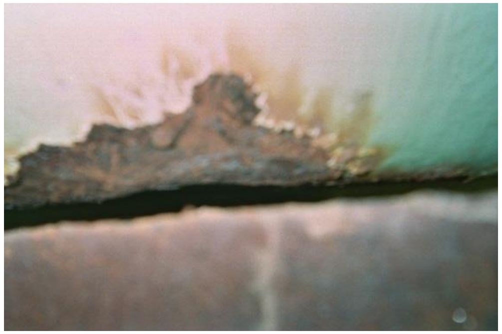
- Torsional mode axial propagation
  - Select correct equipment options and set-up
  - Screen many from on accessible position (cost efficiency)
  - P/E test configuration with SNR limits (corrosion type)
  - Accurate calibration for DAC setting
  - Limitations, range and confidence
  - Prove up (no matter how limited) where possible
  - Compare results for improved accuracy and confidence
  - Prove-up with QSR1
- Circumferential or axial propagation QSR1…

Example – corrosion patch

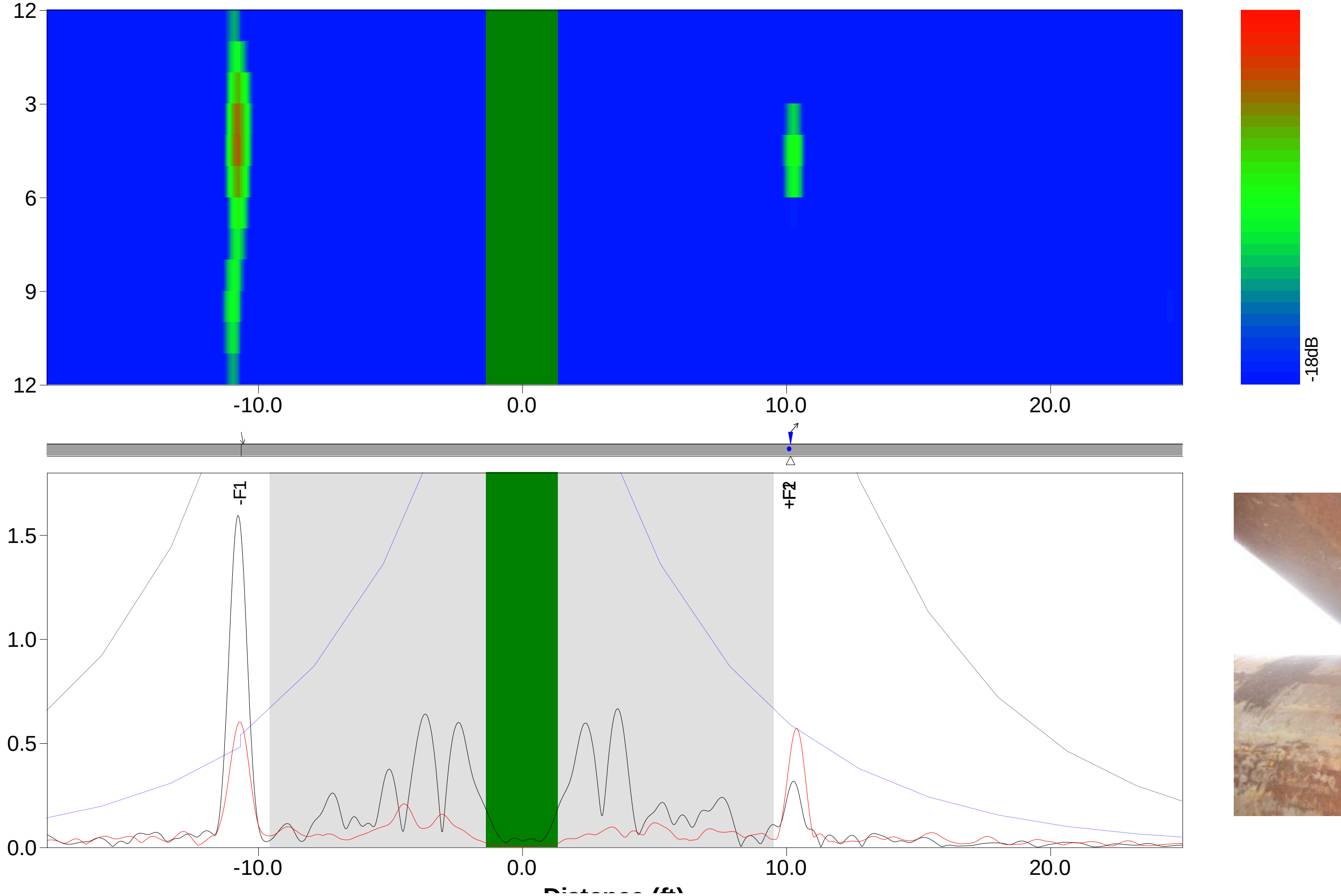


Example – pitting corrosion





Example – wear to pipe



Corrosion monitoring using guided waves

- GWT needs access to the pipe – often this accounts for a large fraction of the inspection cost

- Safety implications of accessing the site, for example excavations, working at height, hazardous areas

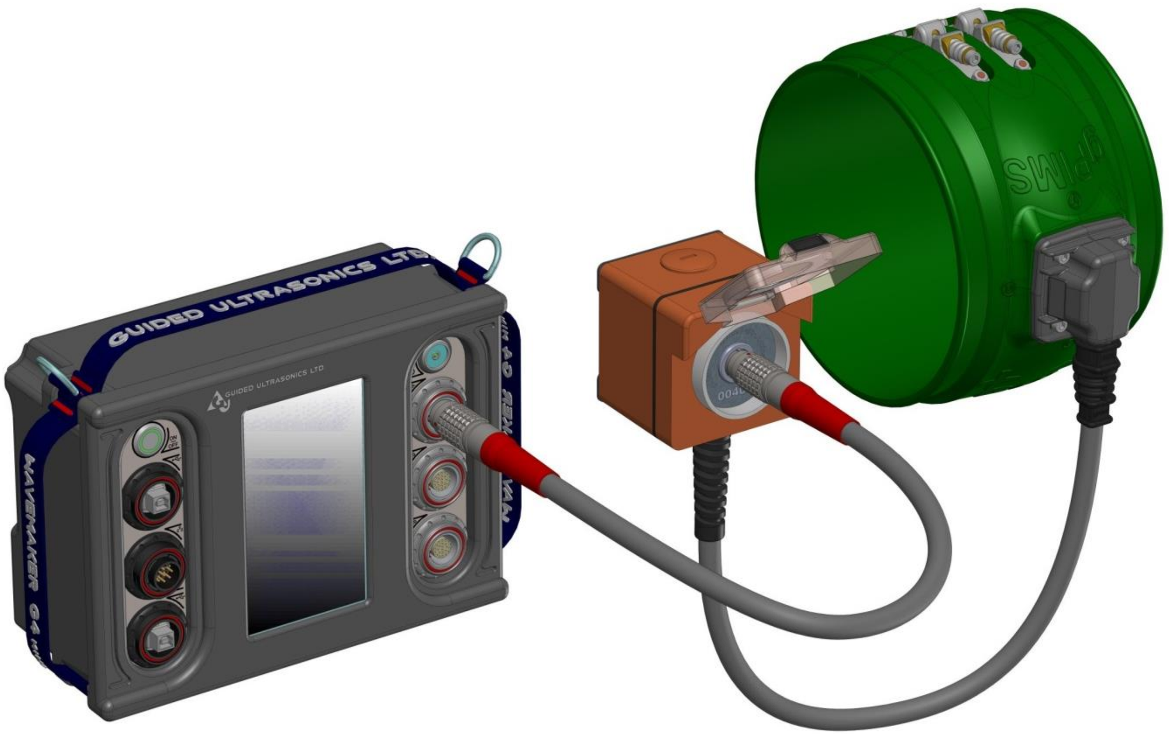
- Recurrent testing for monitoring pipe condition can therefore be costly and carry risks

Permanently installed sensors gPIMS®

- Simplifies recurrent inspections
- Access to test point only required once, then reduces or eliminates access costs
- Increased coverage and sensitivity
- Simplifies comparison of data by subtraction from baseline result
- Enables tracking and trending

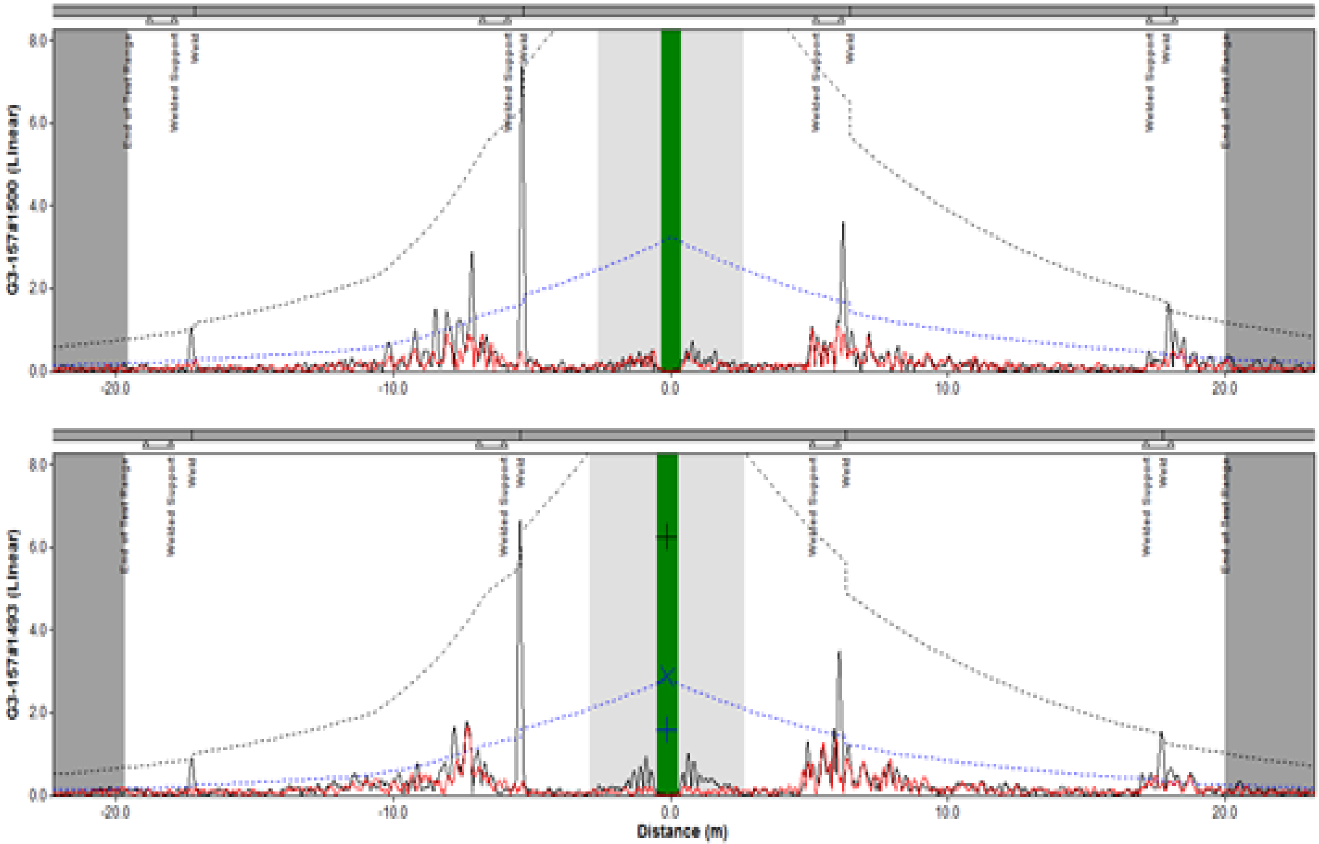
Permanently installed sensors gPIMS®

- Easy-to-install array sensor bonded to the pipe
- Connection box with cable leading to sensor
- Data collection via any 4th generation Wavemaker instrument



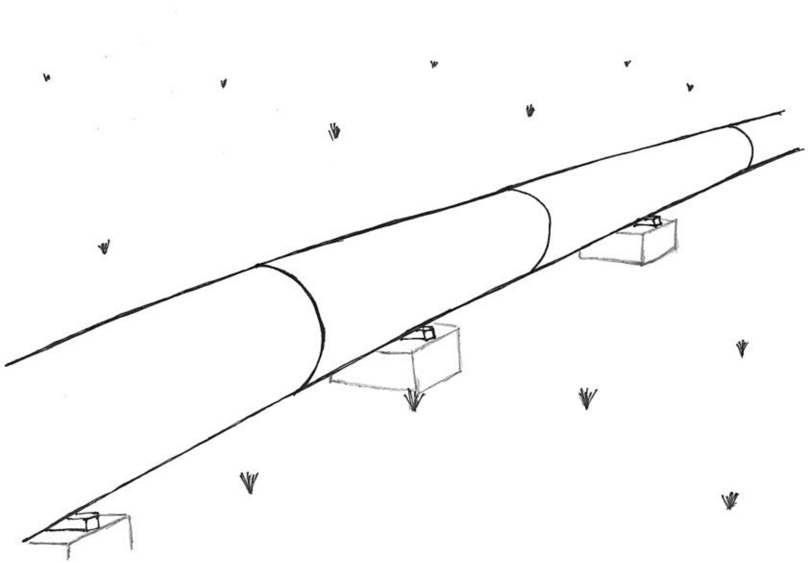
Corrosion Monitoring with gPIMS®

- Looking for differences between repeat tests
- Thousands of results each year

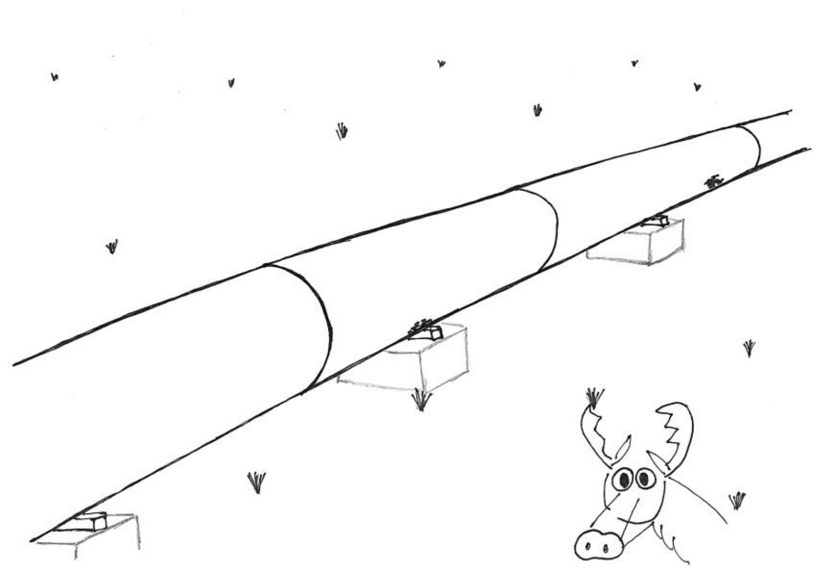


Data interpretation – what is the difference?

Before

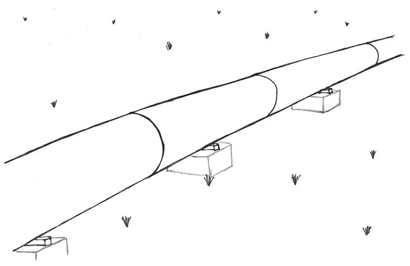


After

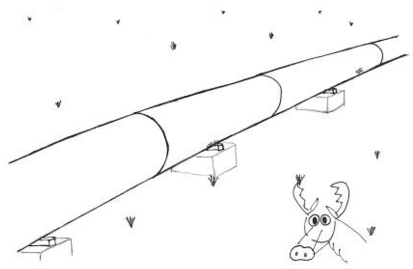


Subtraction of two data sets

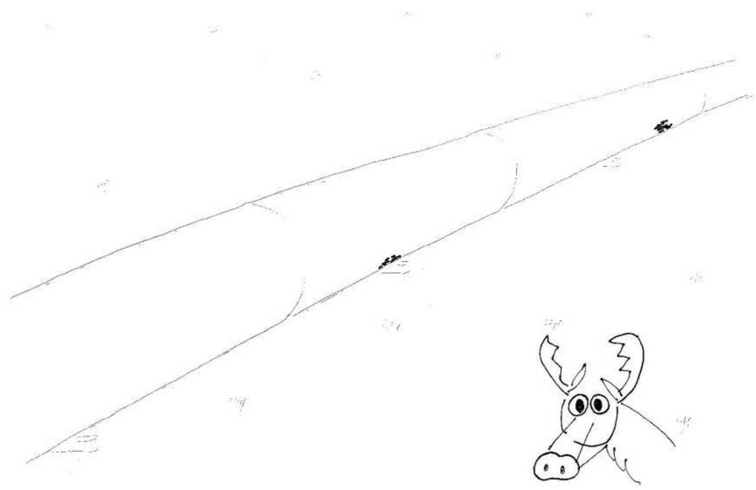
Before



After



Residual



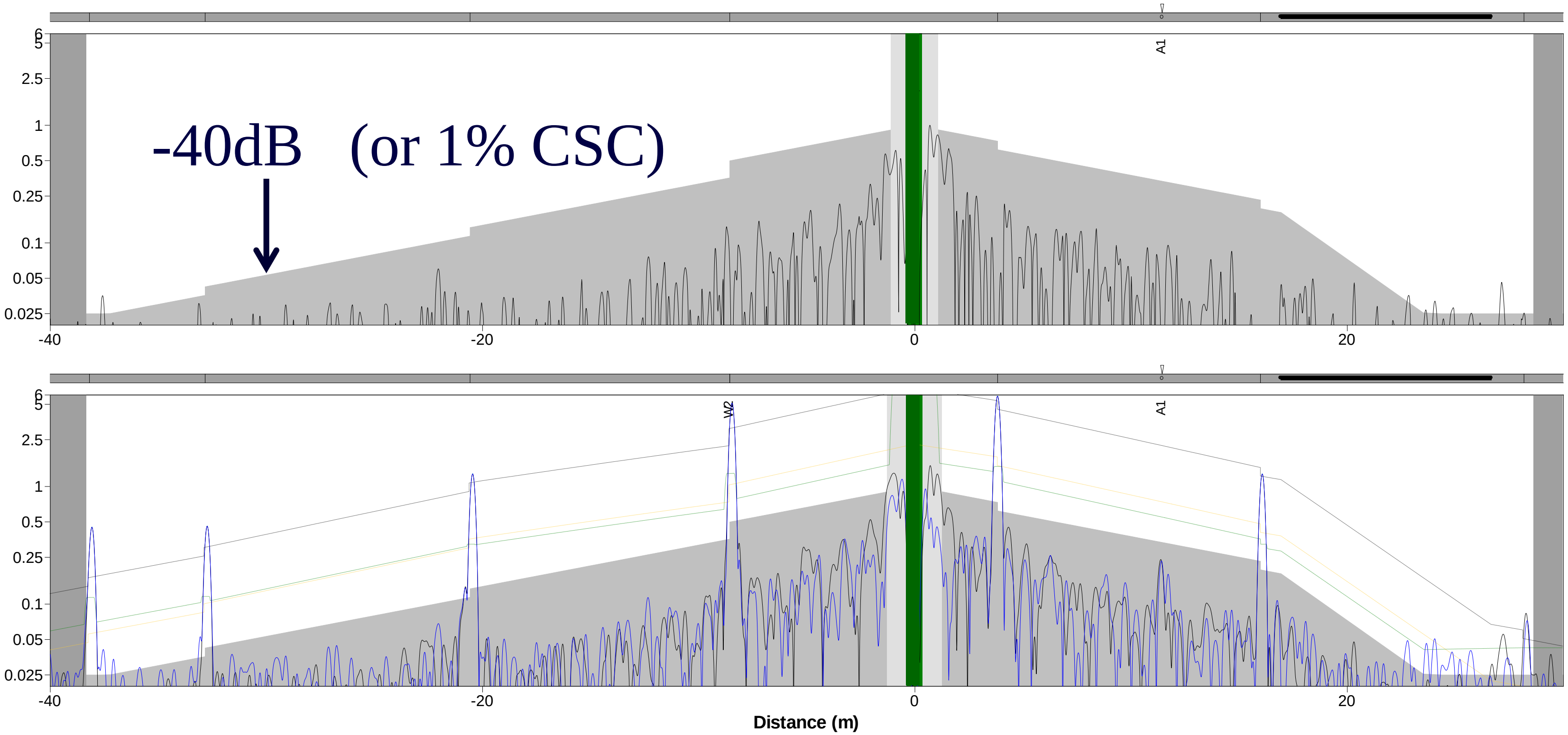
Advanced subtraction required

Compensation algorithm

- Baseline at a certain temperature
- Decide on some reference features such as welds
- Stretch current result trace so amplitude and position of reference features aligned
- Then subtract

Managing changes in result traces

- Features now suppressed, leaving a small residual



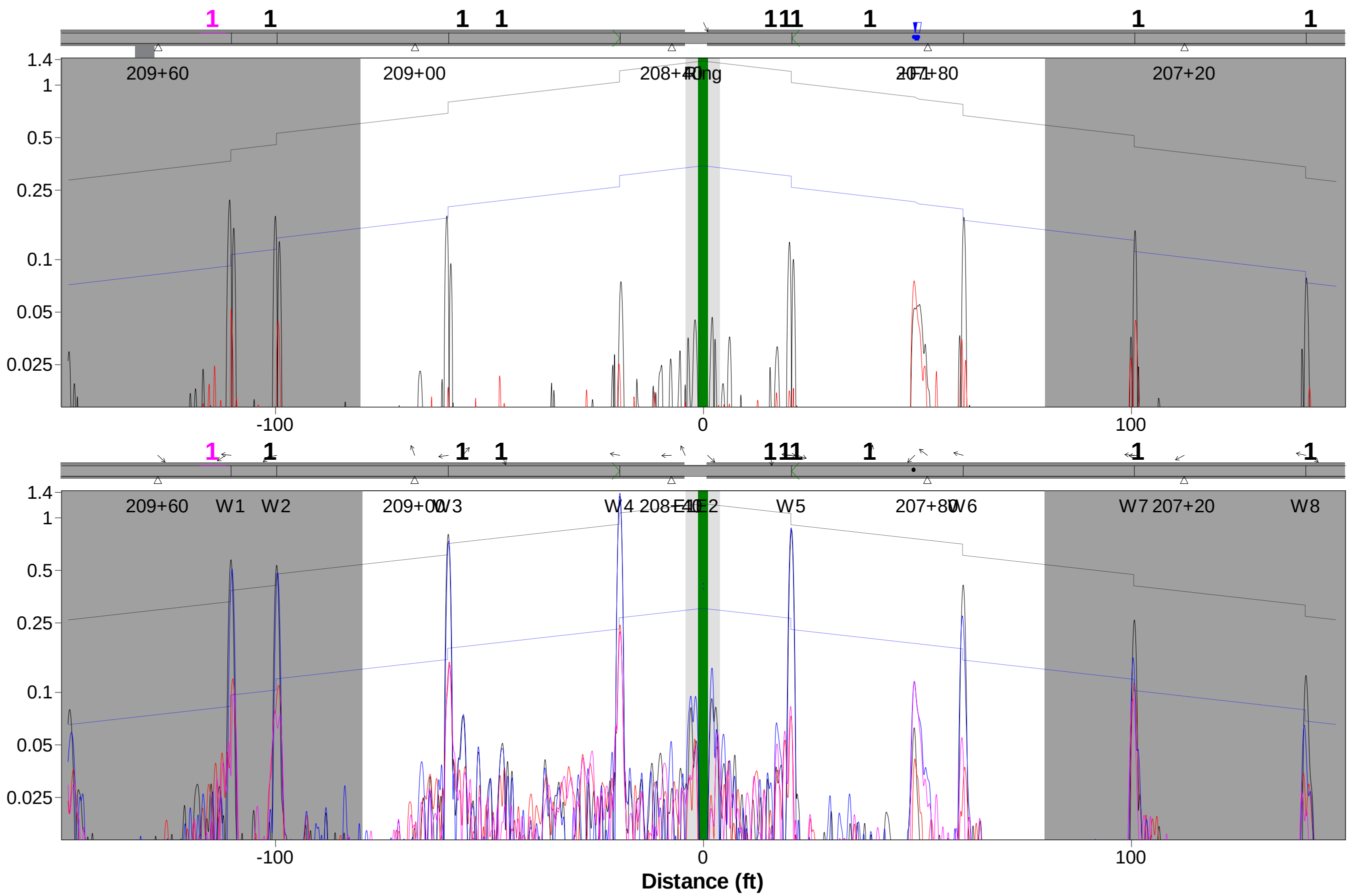
Efficiency of baseline subtraction

- In order to achieve a residual of about -40dB or 1%, the current result should not be more than 5 - 10° C different from the baseline
  - This generally necessitates more than one baseline

- Therefore the recommendation is to collect as many baseline results within the first year of operation as possible
- Specially developed monitoring software can automatically choose the optimum baseline to use for best subtraction efficiency.

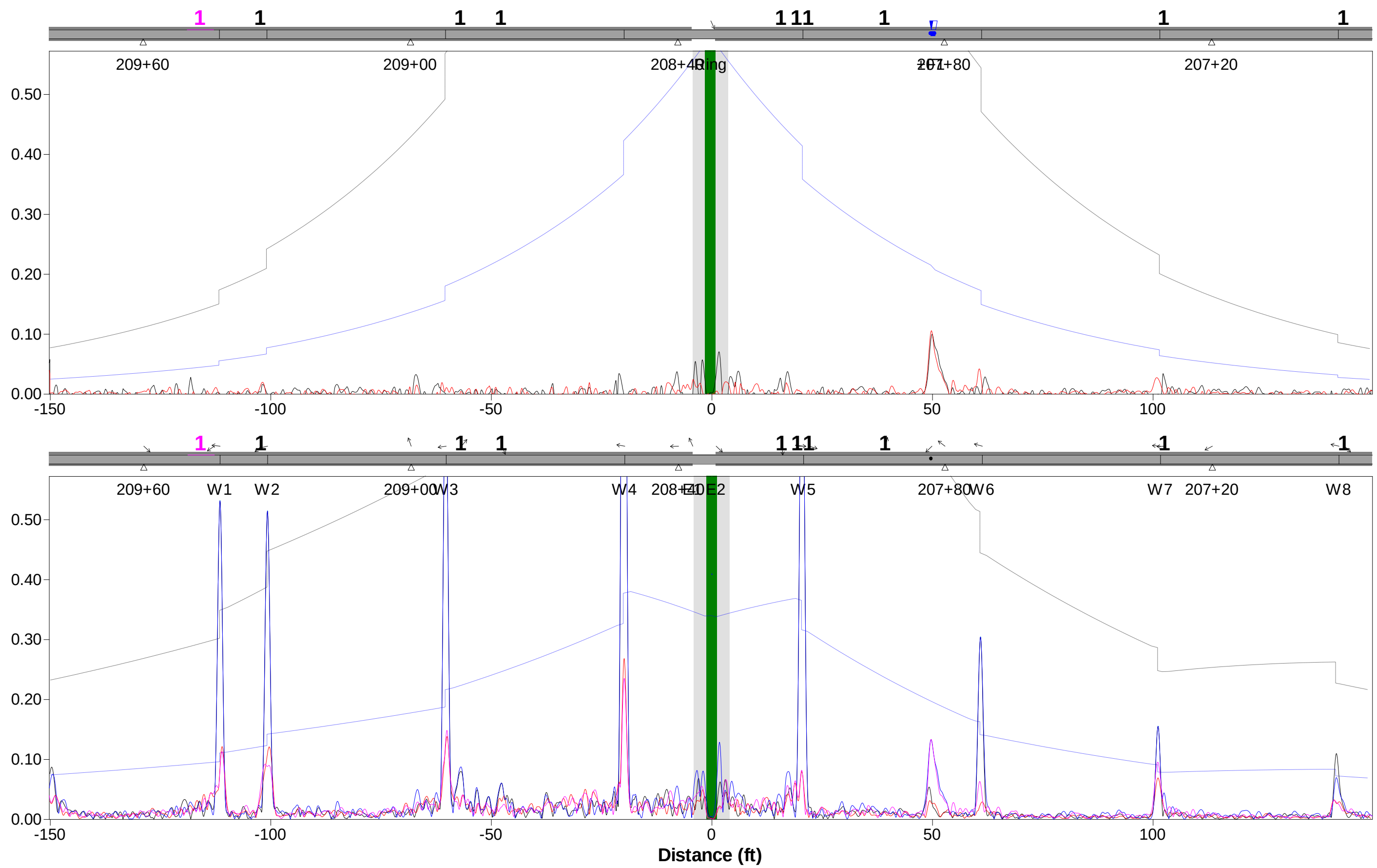
Corrosion monitoring example

- Basic subtraction



Corrosion monitoring example

- Advanced subtraction

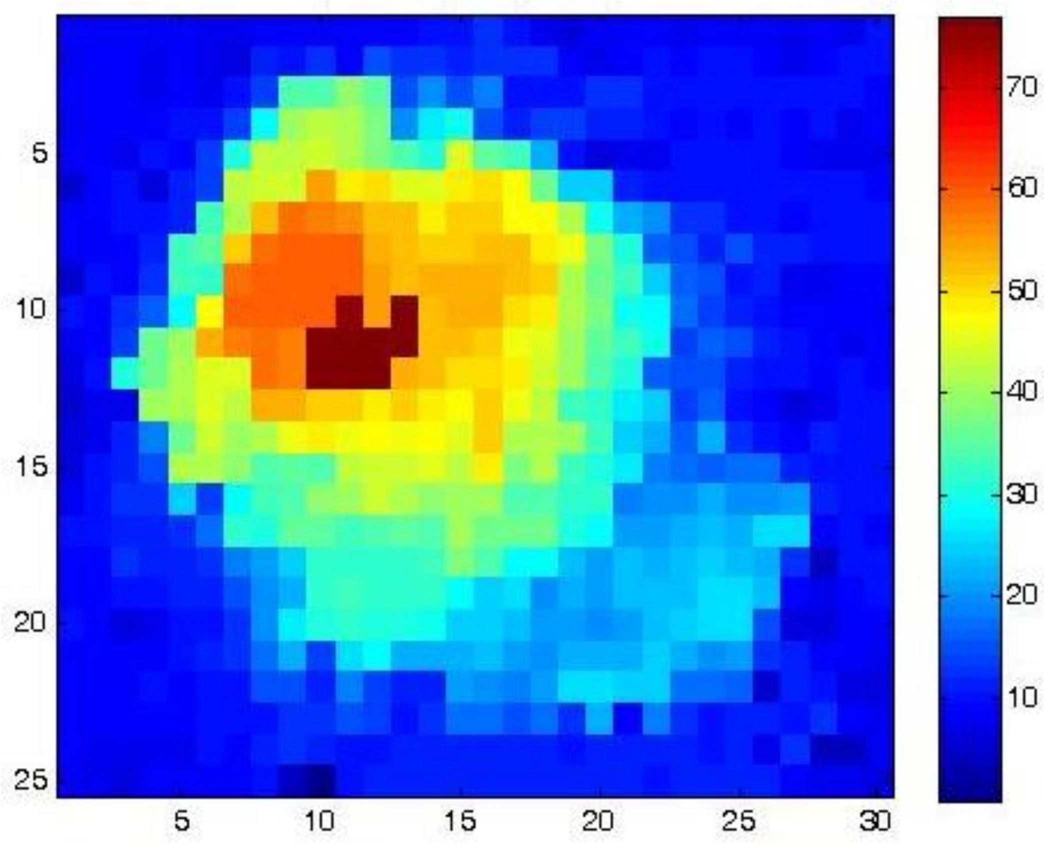


Corrosion Under Pipe Supports (CUPS)

Quantitative Measurement of Corrosion Under Support

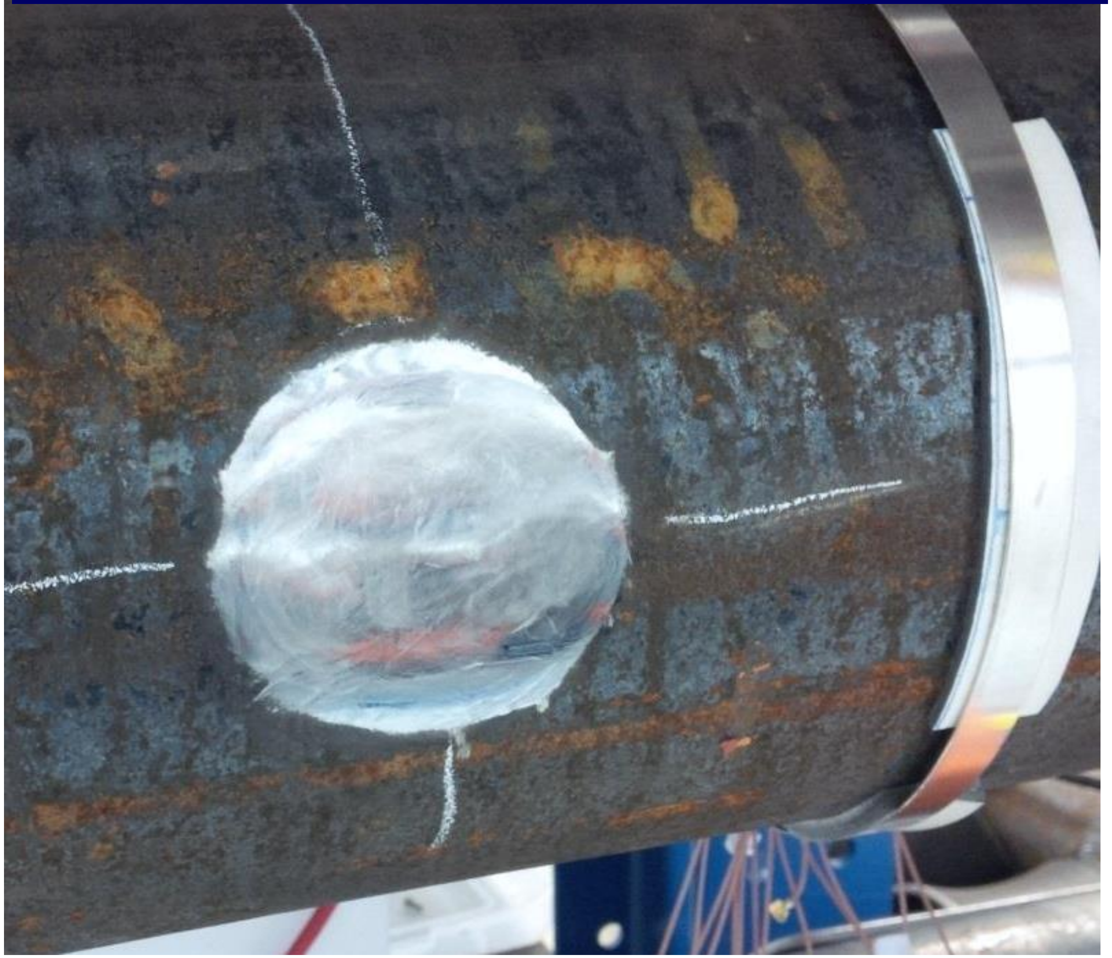
Different Concepts…

Aim of Short Range Testing



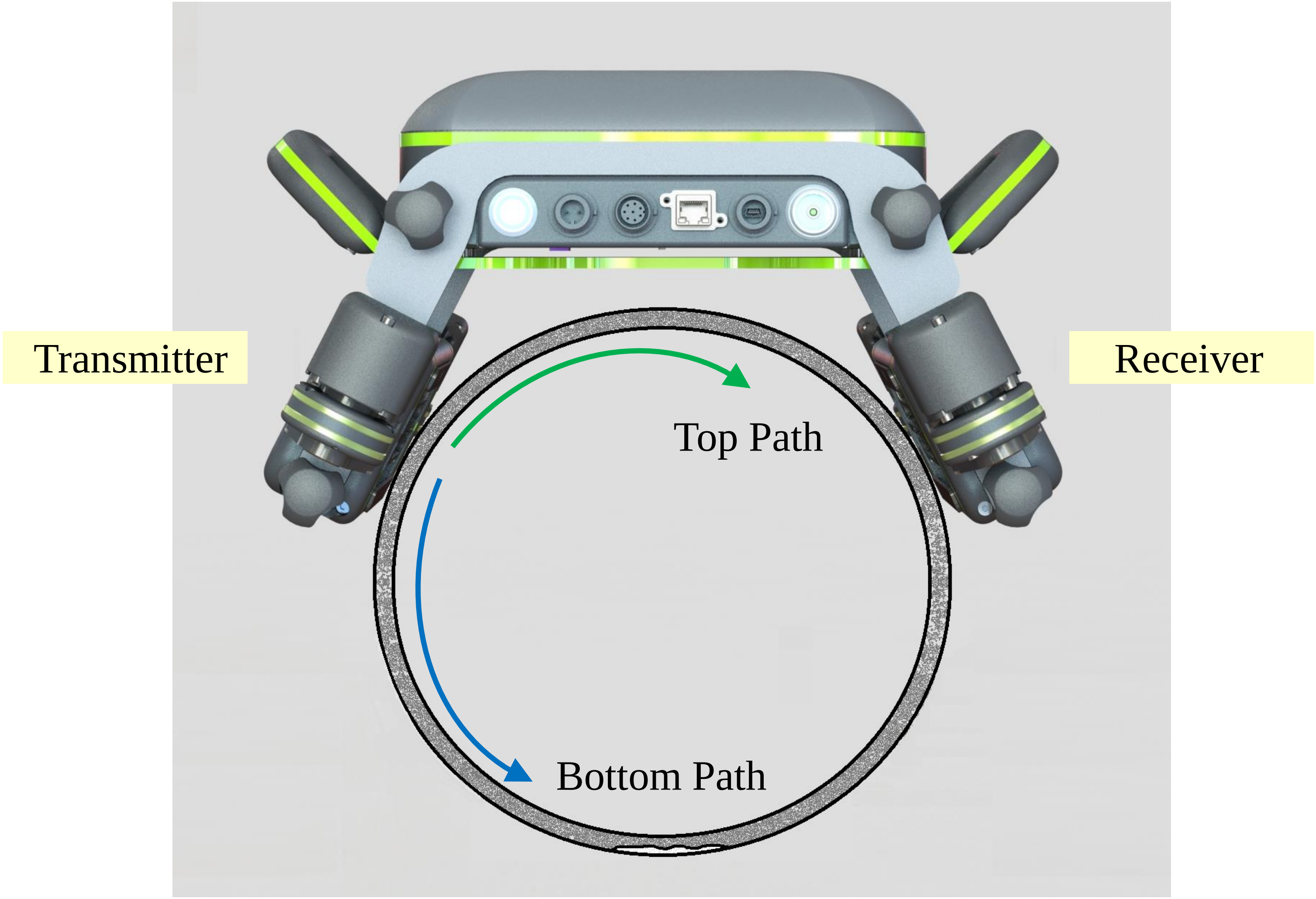
- Tomography approach
- Produce map or profile of depths of corrosion
- Critical parameter is maximum depth

Tomography Attempt - 2015



- Tomography approach
- Produce map or profile of depths of corrosion
- Critical parameter is maximum depth

QSR1 measurement parameters



QSR1 - Short Range Scanning

Circumferential Guided Waves used to **Measure Wall Thickness**.

Multiple families of modes
Dispersive modes

At each location scanned the QSR1 system automatically measures:

The pipe diameter
Distance between Transmitter and Receiver
Top Path wall thickness
Bottom Path wall thickness
Bottom Path **Minimal Wall Thickness**.

Quantitative measure of average wall thickness.

Quantitative measure remaining minimum wall[1].

Estimates where the wall loss location is.

Adapts to different pipe wall thickness.

Notes:

1 : Down to about half of the nominal wall thickness (and report any areas with less than half nominal wall

Quantitative Short Range - QSR1

Guided Ultrasonics are currently working on an innovative testing system QSR1 to quantitatively measure corrosion at supports.

QSR1 automatically measures the size of corrosion to the depths of up to half of the pipe wall thickness.

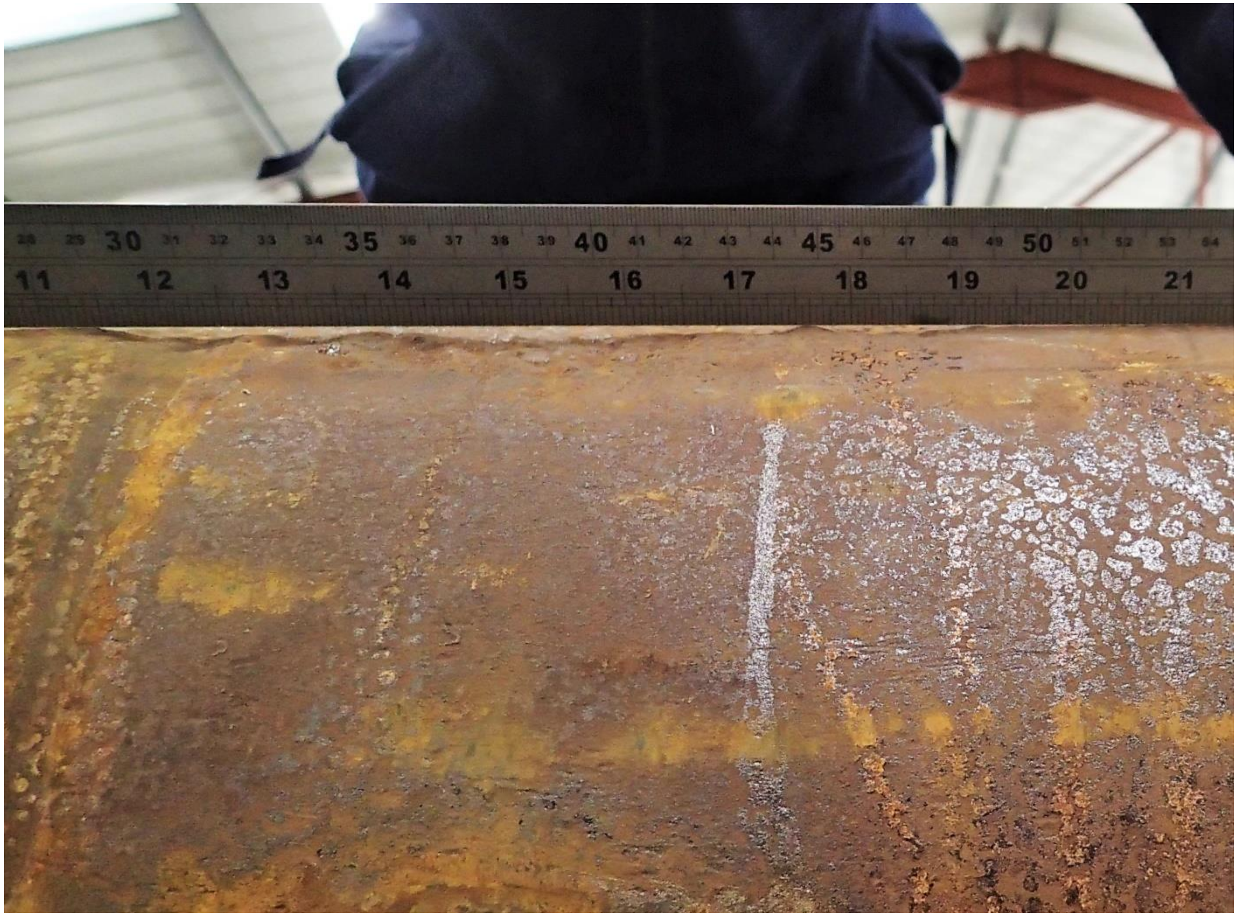
QSR1 also automatically measures pipe diameter and pipe wall thickness around the pipe circumference from a single location in a fraction of a second.

Quantitative Short Range - QSR1

Ex-service 12 inch pipe with the hidden Corrosion Under Pipe Support (CUPS) type defect was scanned by QSR1 in order to obtain the profile of the area.

Quantitative Short Range - QSR1

The scanned defect was then visually examined and the QSR1 scan was compared with the reference laser scan of the area.



Quantitative Short Range - QSR1

Very good agreement was achieved between the laser scan of the defected area (red line) and the QSR1 measurements (blue line).

Conclusions

- Over the last 20 years pipe screening for corrosion has become a powerful method in different industries.
- Screening long lengths from a single location and in a single test generates big savings when inspecting or monitoring.
- Continuous innovation and developing new devices to improve sensitivity and coverage has been critical to success.
- The new Quantitative short range screening technology together with cloud computing and artificial intelligence will facilitate new levels of industrial adoption.