PRCI MD 1-6: Ultrasonic Measurements of Strains in Pipelines **DOT Project #372,** Direct Strain Measurements and Failure Pressure Prediction in Mechanically Damaged and Strained Pipes

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Applied Research Associates, Inc.

Adjunct Professor, College of William & Mary, Virginia Institute of Marine Science

PRCI Pipeline Program Research Exchange Meeting

Wednesday, February 9, 2010

About Applied Research Associates, Inc.

- Founded 1979, Albuquerque, New Mexico
- 1,446 Employee Owners at locations in the U.S. and Canada
- FY 09 Sales of $213.2 million

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Motivation for strain measurement

- There is a need to determine the integrity of pipelines to decide:
  - Repair actions
  - Replacement timing
  - Continued operation at reduced pressure

- Current in-service NDE measurements
  - Detect cracks and corrosion very well

- Strain is needed to ensure reliability
  - ASME code for pipelines is strain based
    - > 6% strain for plain dent – repair or replace
  - To predict maximum operating pressure
  - To ensure proper strain based design

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Outline

- Motivation and history
- PRCI and PHMSA work plan
- Background from DOE work
- Results from current PRCI and DOT projects
  - Lab
  - Field work
- Applications to dents
- Future directions
- Proposed PRCI Project

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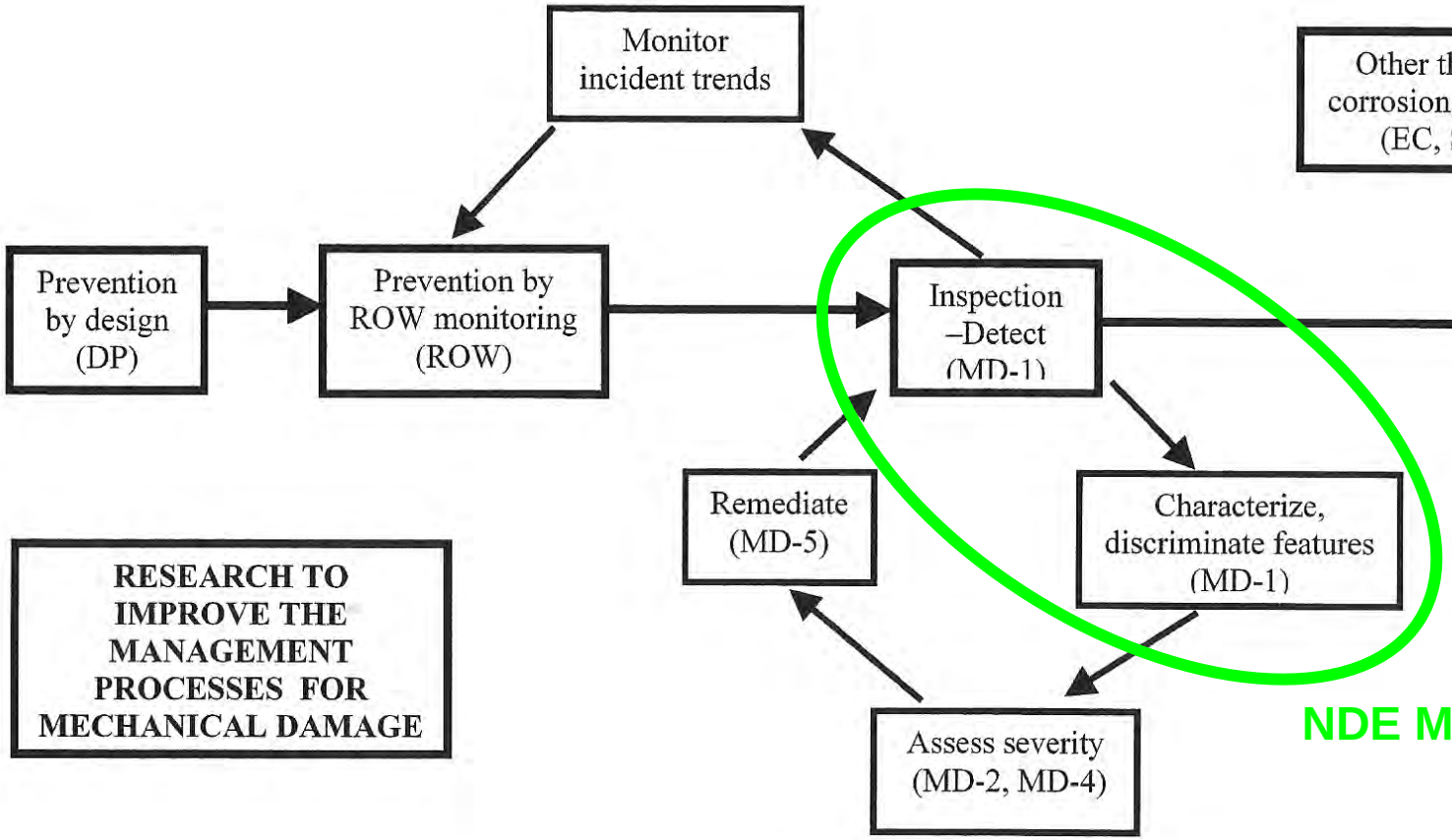
Pipeline Research Council International Perspective on Pipeline Integrity – Mechanical Damage



David Batte - PRCI Subject Matter Expert

Presented at: Research Exchange, Atlanta, February 2009

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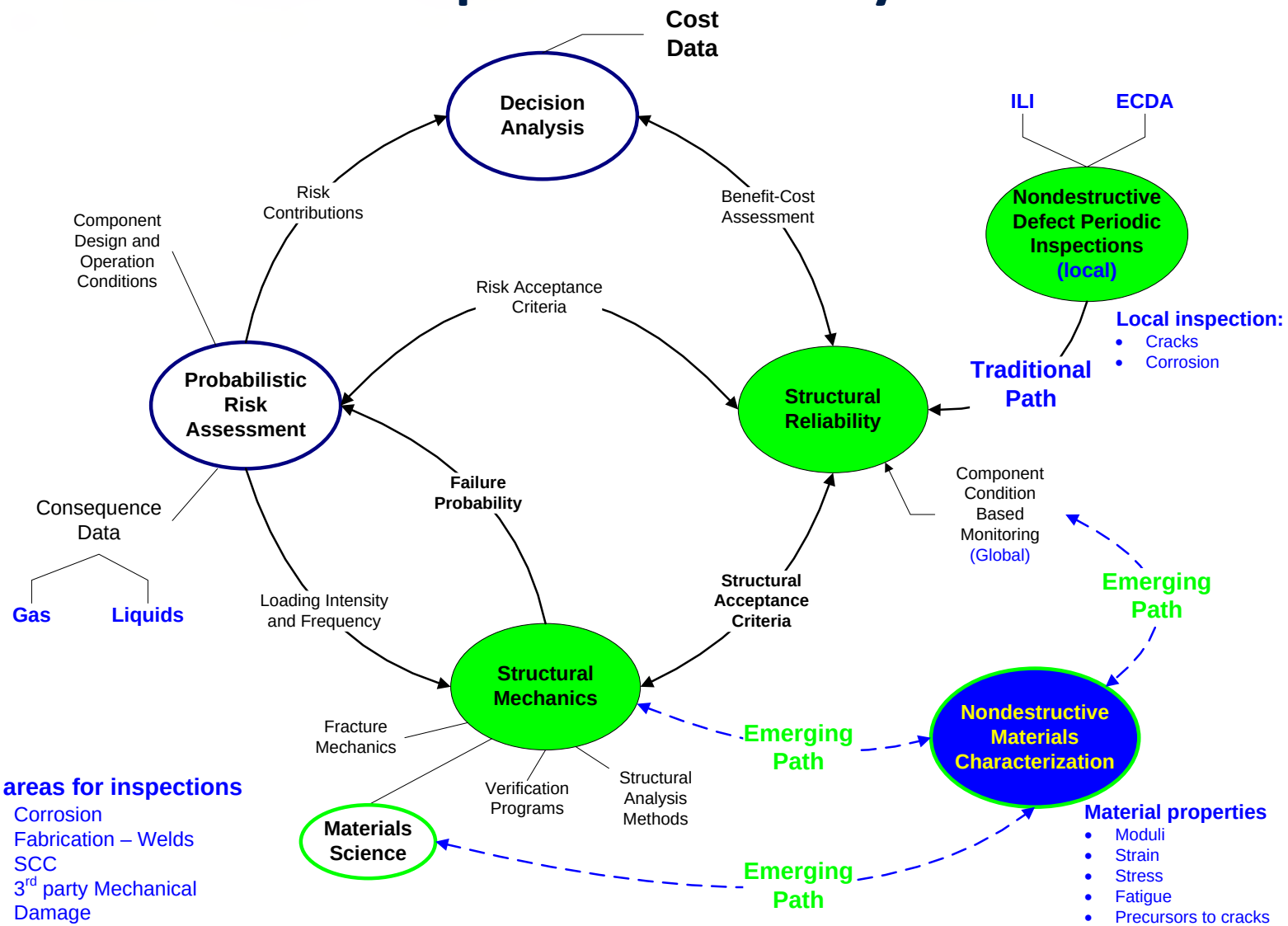
Pipeline reliability



Prepared by: S. R. Gosselin, P. D. Panetta, and A. Van Roodselaar

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History Strain Measurement - Background work

NIST – GRI Project 1999 with George Alers – NIST Bent Pipe

DOE NETL Project while Paul Panetta was at Pacific Northwest National Lab ($1.1M)

- Dogbone specimens (2000)
  - Tensile tests
  - Methodology development
- Pipes
  - Pressure test
  - Calibrated dents

Industry Interactions

- Pacific Gas and Electric
- BJ Inspection Services
- Southern California Gas

Field work

- Burst pipes – PG&E
- Dented pipes – **Ranked severity based on strains** – DOE/DOT Demonstration - 2004
- Gouged pipes – DOE/DOT Demonstration Test - 2005
- **Bulged pipe – With Battelle – 2005**
- **Bent/Kinked pipes** – PG&E Fault crossing construction site (2005/2006)

DOT PHMSA, 2 year project - Started June 2008, Paul Panetta at Luna

PRCI, 2 year project - Started September 2008 , Paul Panetta at Luna

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PRCI and PHMSA Project Summary

PRCI MD-1-6, Ultrasonic Measurements of Strains in Pipelines,

- Year 1: $93K started, May 2008
- Year 2: $100K proposed, on hold pending 2011 Ballot

DOT Project #372, Direct Strain Measurements and Failure Pressure Prediction in Mechanically Damaged and Strained Pipes

- Start Date June 2008
- DOT Contribution: $288K, 2 years

In kind contributions ($105K)

- Southern California Gas – In kind
  - Site access, technical consulting, pipes
- Pacific Gas and Electric– In kind
  - Site access, technical consulting, pipes
- NIST– In kind
  - Bent pipe, welded specimens
- El Paso Gas
  - Kinked Pipe

Consultants for DOT Project

- Steve Gosselin, Scandpower - burst pressure modeling and probability of failure
- Dave Mauney - financial impacts

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Year 1 PRCI Tasks and Schedule

Task	Sept 08	Oct 08	Nov 08	Dec 08	Jan 09	Feb 09	Mar 09	Apr 09	May 09	Jun 09	Jul 09	Aug 09
1. Equipment Set Up, Lab Tests												
2. Field Work - So Cal Gas												
3. Field Calibration, Data Analysis												
4. Strain Info for modeling												
5. Reporting												

Moved to ARA

Completed tasks

Four technical thrust areas

1. Lab Measurements
2. Field Work
3. Field calibration development
4. Interface with PRCI strain prediction project teams

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PRCI and DOT Project Plan

November- December: Lab work on wrinkle bend pipes from field

December 2009 – January 2010:

- Field work
- Ultrasonic modeling (DOT Tasks)
- Burst Pressure Modeling (DOT Tasks)

January – February 2010:

- Data Analysis
- Ultrasonic modeling (DOT Tasks)
- Burst Pressure Modeling (DOT Tasks)

February 9 – 11, 2010 PRCI Research Exchange meeting:

- Present Results

February – March:

- Write and submit report

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Results to date

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Bent Pipe from NIST

Thank you Dave McColskey

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Wrinkled Pipe from El Paso Gas

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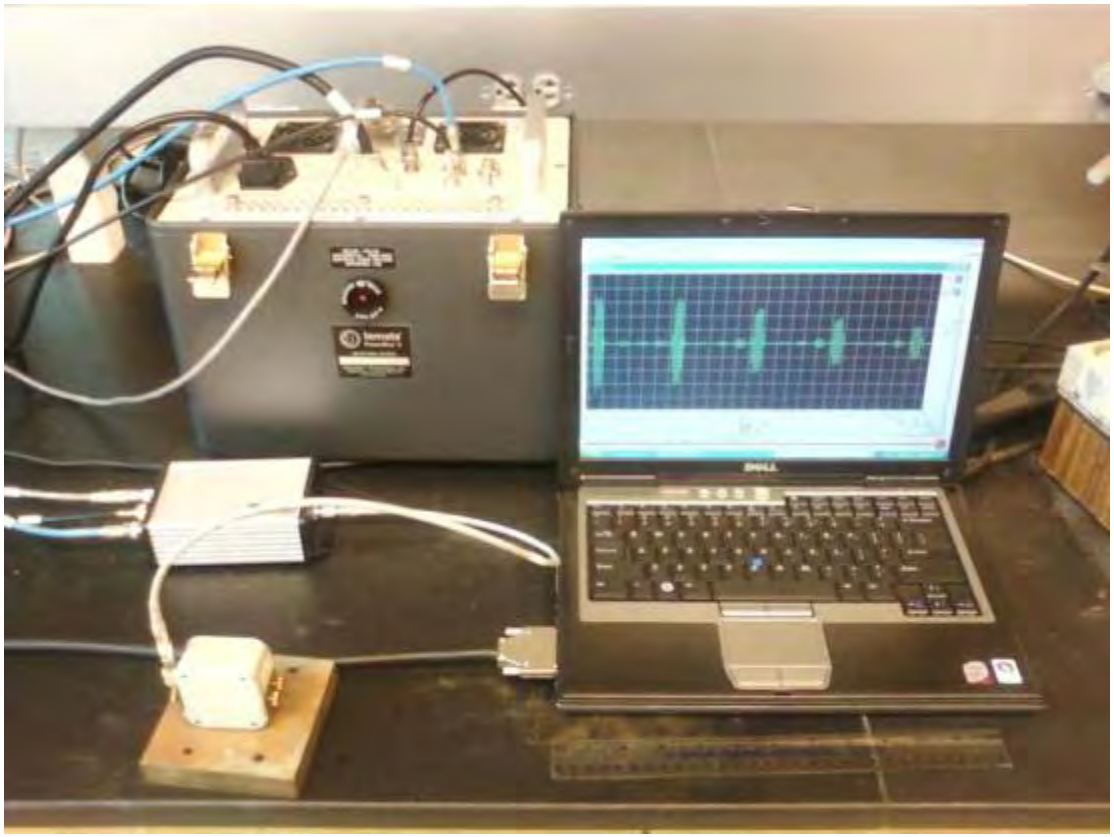
Thank you Satish Kulkarni

EMAT Equipment



Benefits of EMATS

- No coupling
- Works well on rusty surfaces
- Easy to scan
- Reproducible measurements

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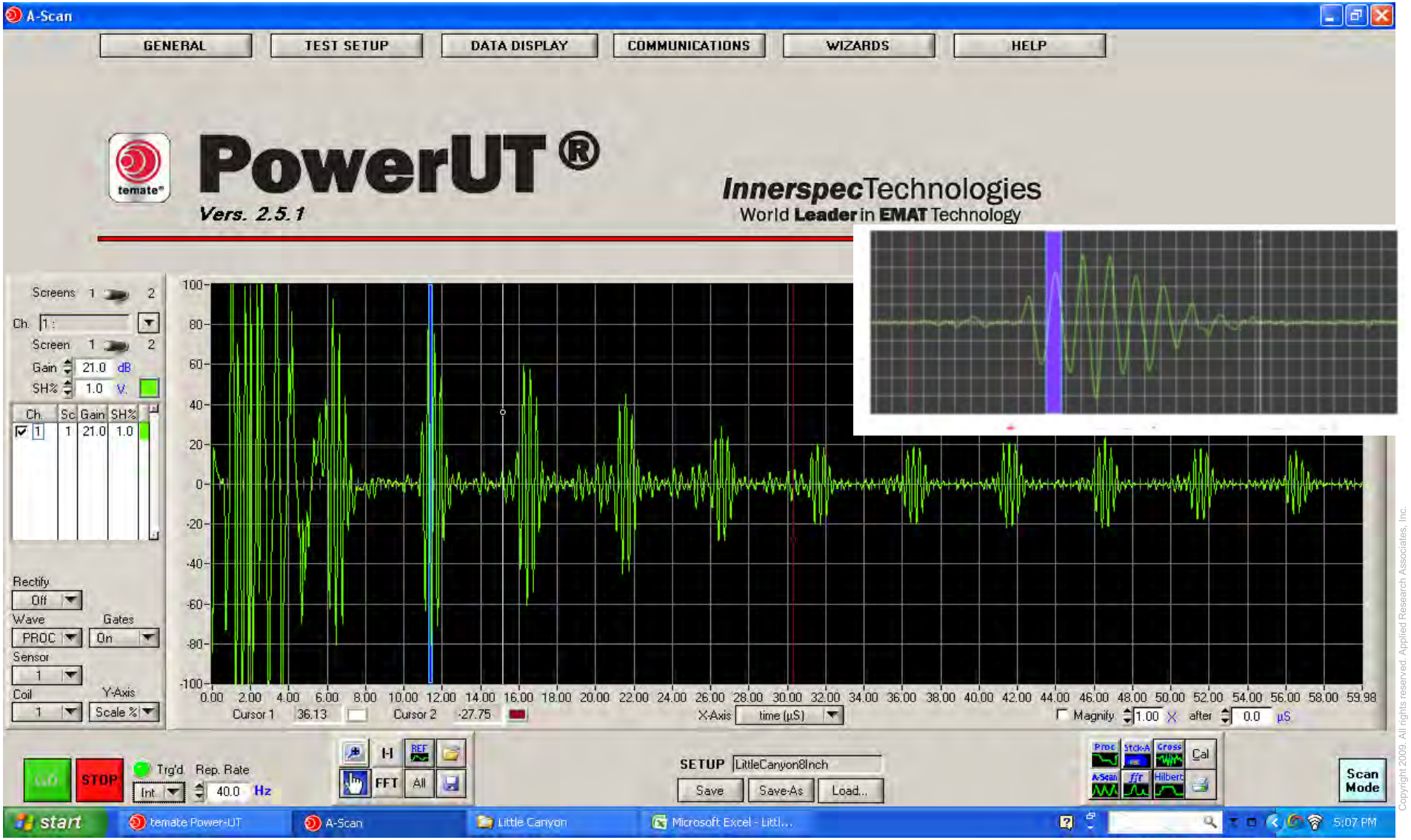
EAMT waveform



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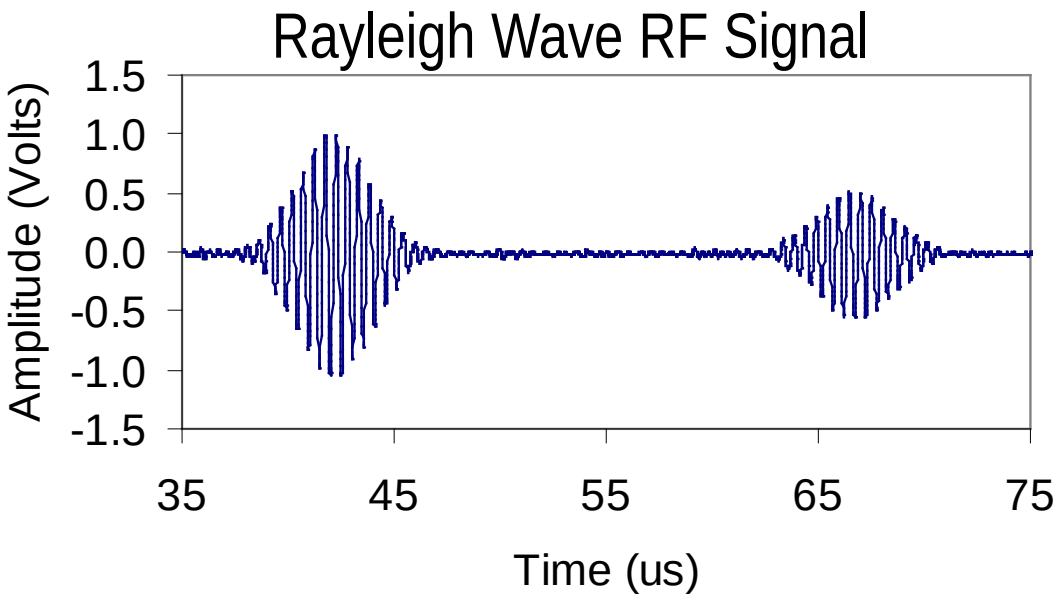
Lab measurements during tensile test

Tensile tests



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Ultrasonic theory uniaxial stress

L-wave $$\rho\ V_{33}^2 = C_{33} = B + \frac{4G}{3} + 4.786 C_0 \mathbf{W_{400}} + K_1\sigma$$

Moduli — Texture — Stress

Shear

$$\rho V_{31}^2 = C_{31} = G - 6.381 C_0 \mathbf{W_{400}} + 10.089 C_0 \mathbf{W_{420}} + K_2\sigma$$

$$\rho V_{32}^2 = C_{32} = G - 6.381 C_0 \mathbf{W_{400}} - 10.089 C_0 \mathbf{W_{420}} + K_3\sigma$$

Polarized Parallel to applied stress

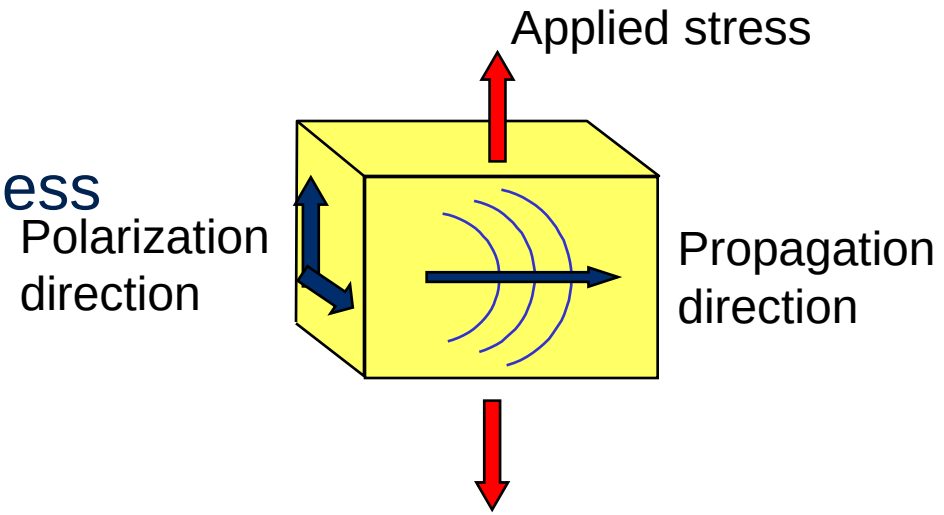
Polarized perpendicular to applied stress

Birefringence is independent of thickness

$\mathbf{W_{lmn}}$ - texture parameters

K_I - acoustoelastic constants

σ - tensile stress



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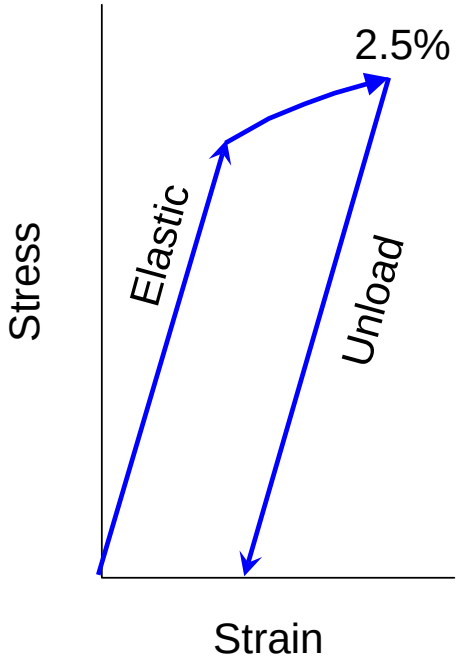
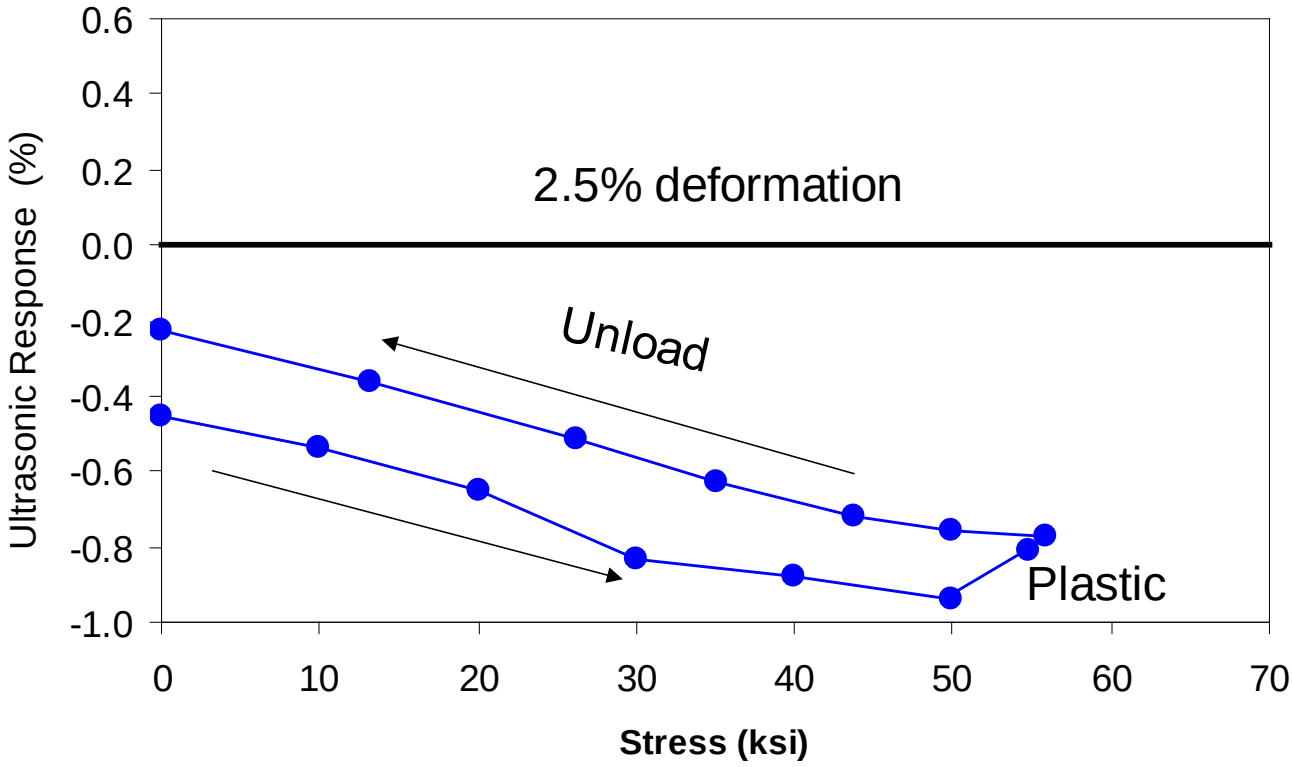
Birefringence during plastic deformation





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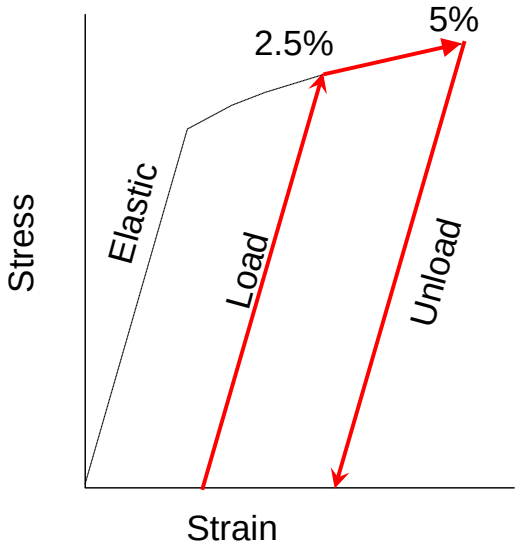
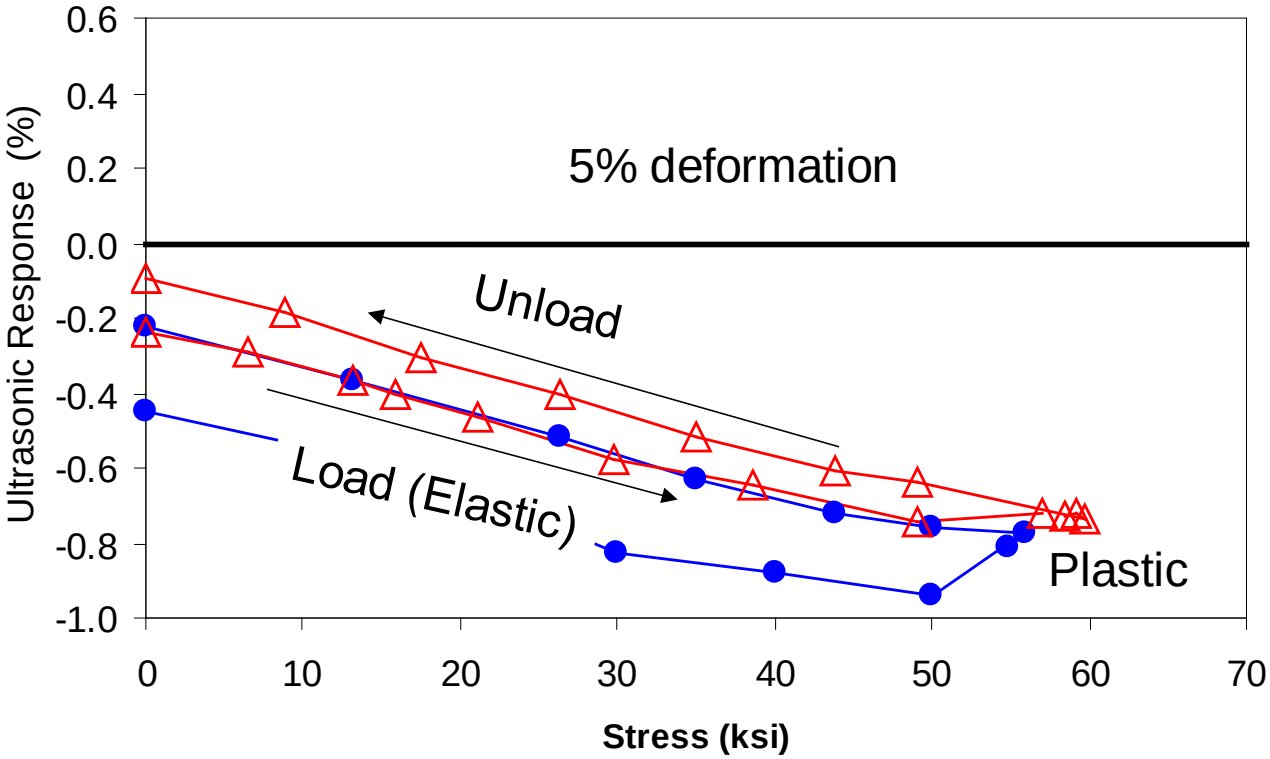
Birefringence during plastic deformation





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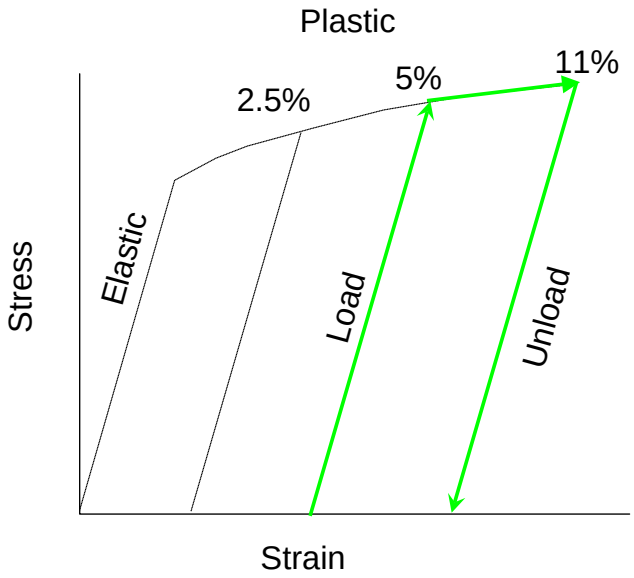

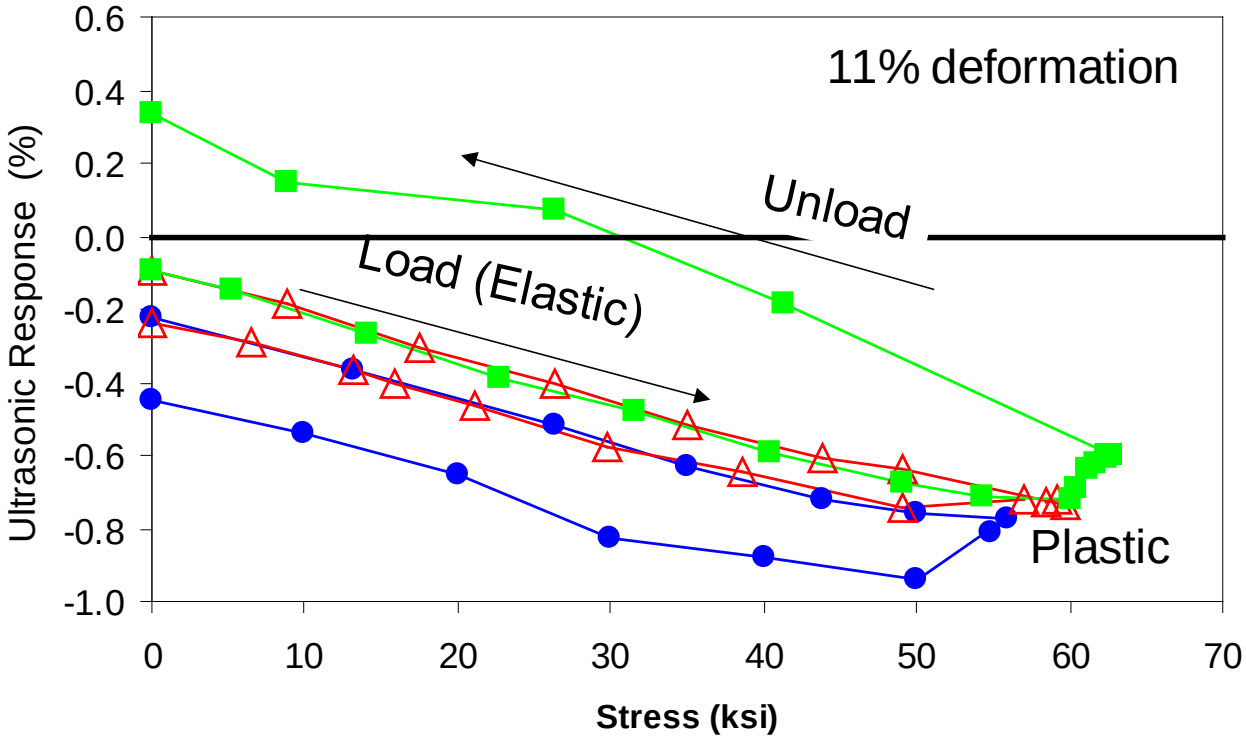

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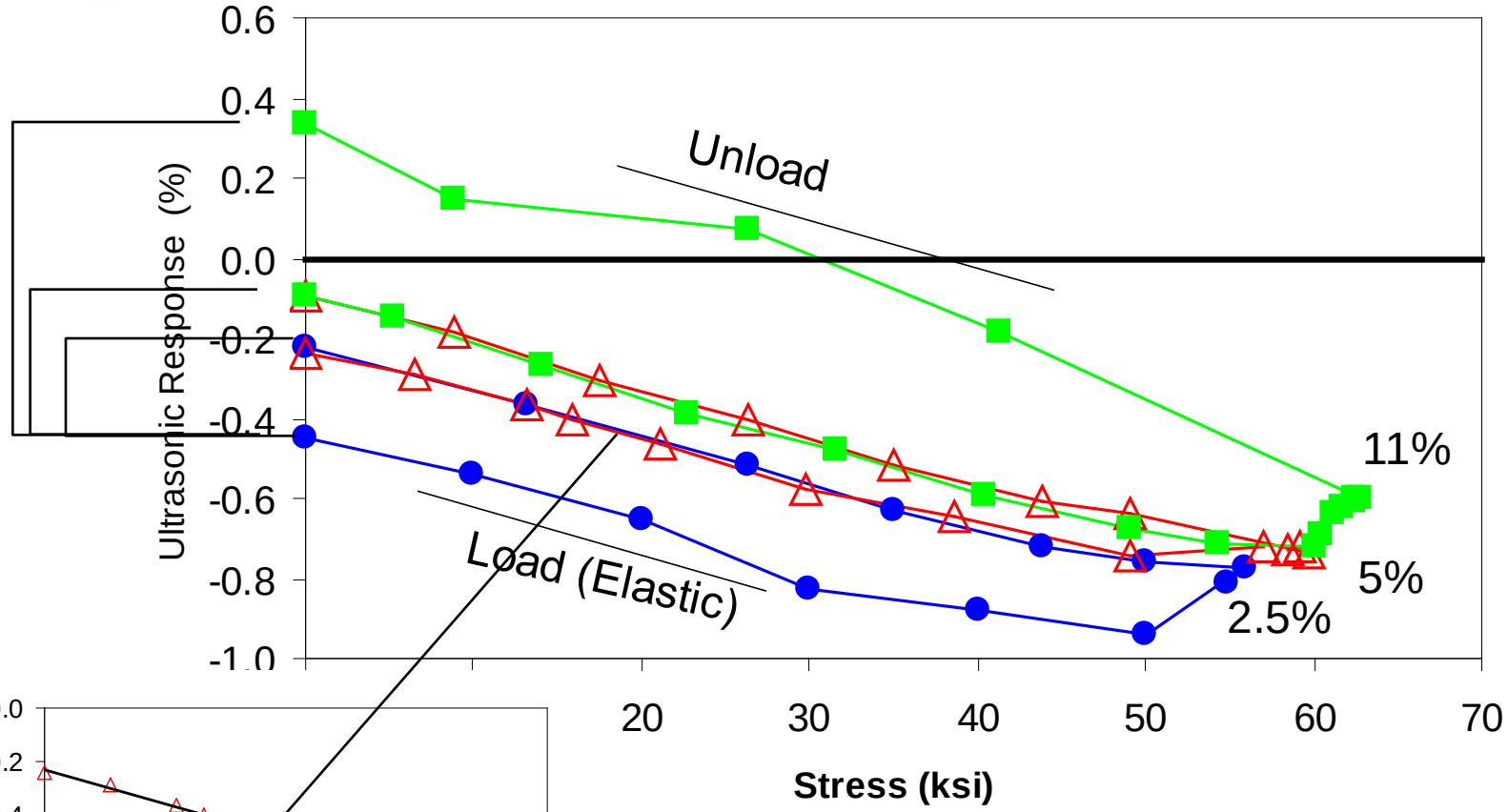
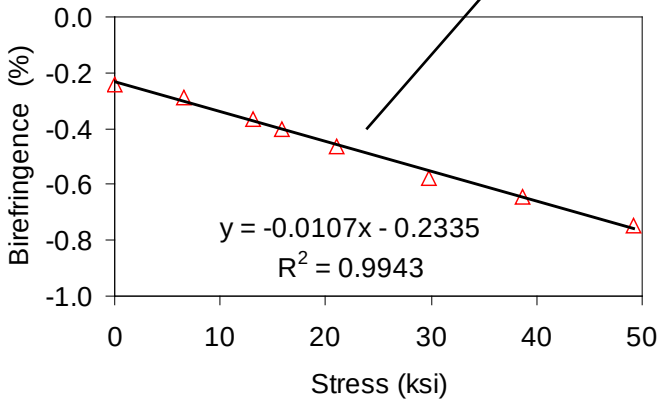
Birefringence during plastic deformation





Slope in elastic region = -0.01 % / ksi
Use to determine stress effect

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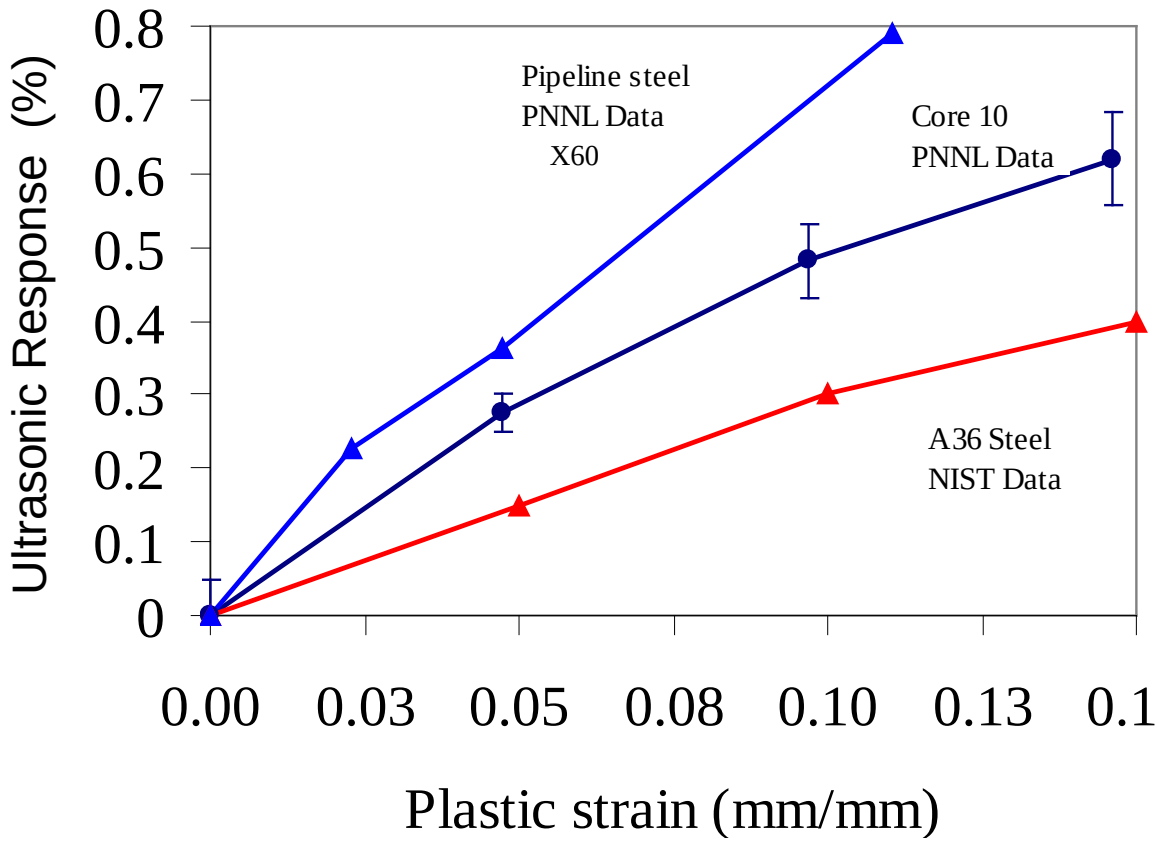
Change in birefringence as a function of plastic strain



This data shows there is a potential for a data base

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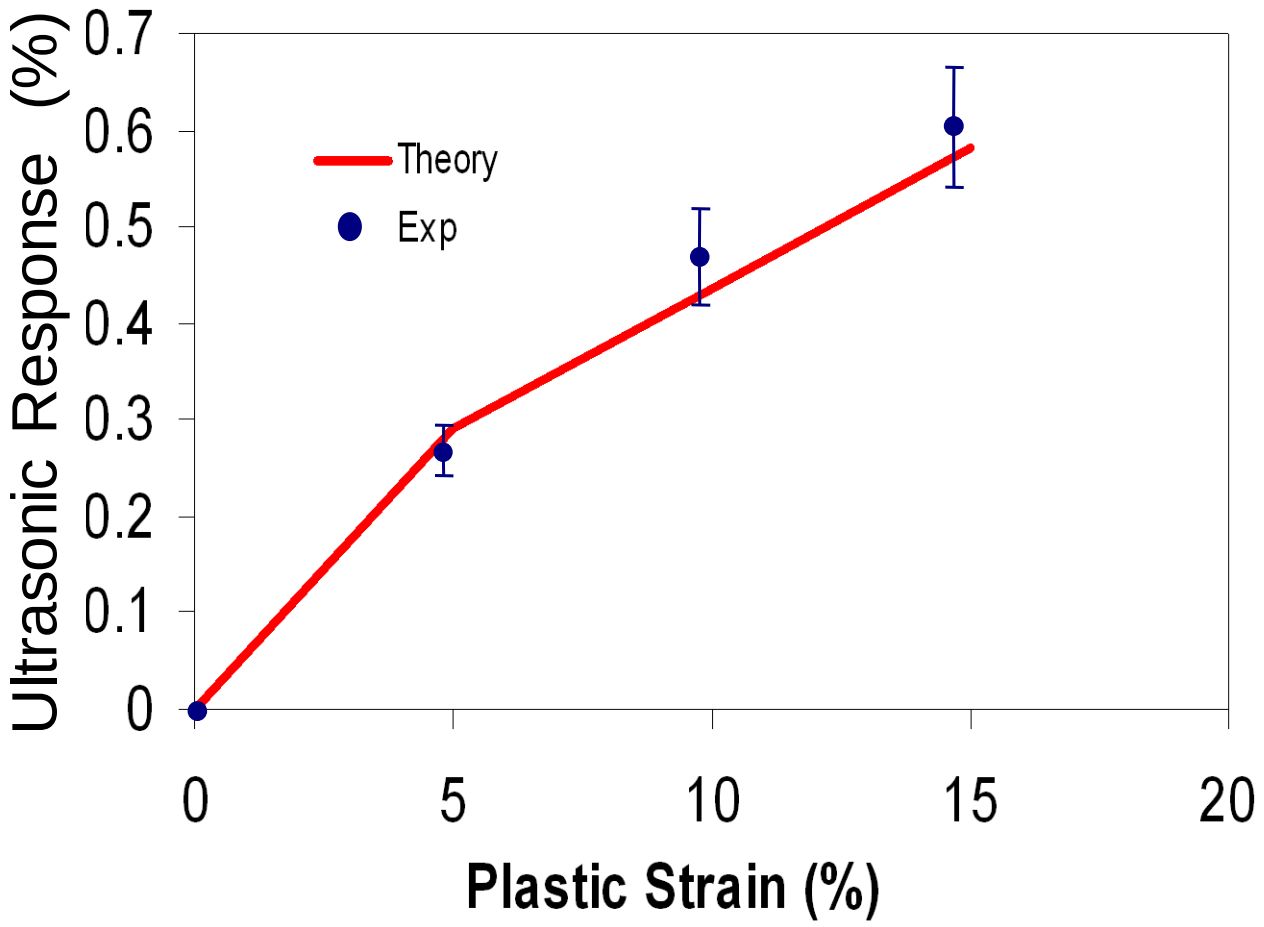
Birefringence – Excellent agreement with theory before and after deformation – Mechanics Approach

Assumptions:
- Stress free
- Known baseline



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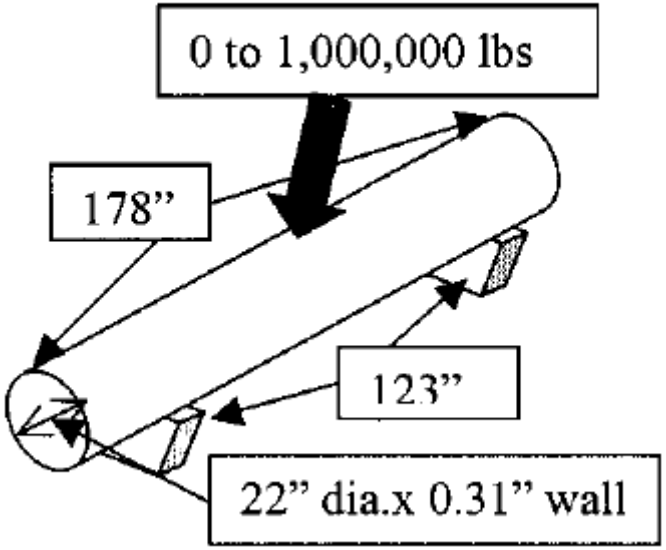
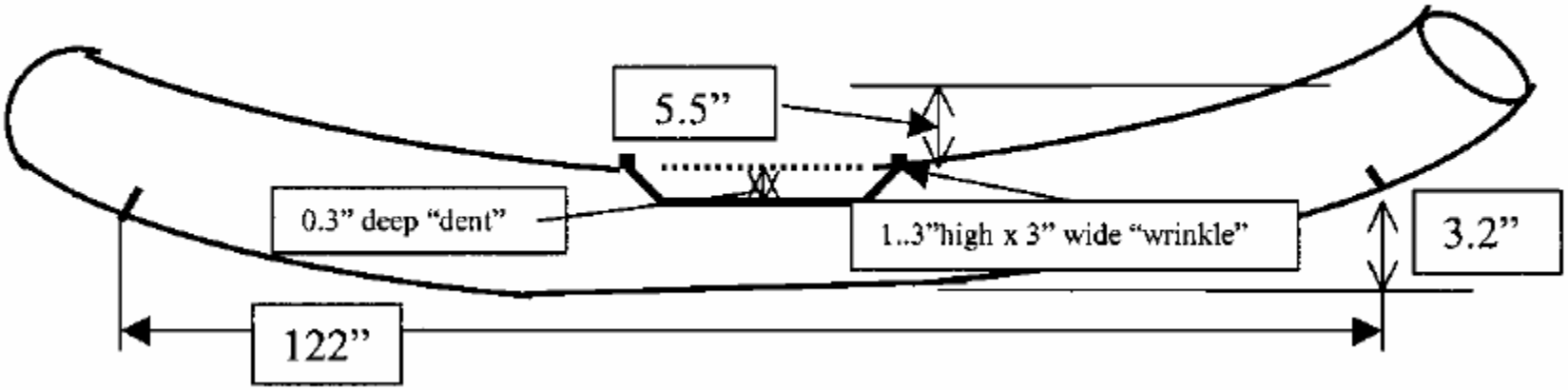
Schematic of NIST bent pipe





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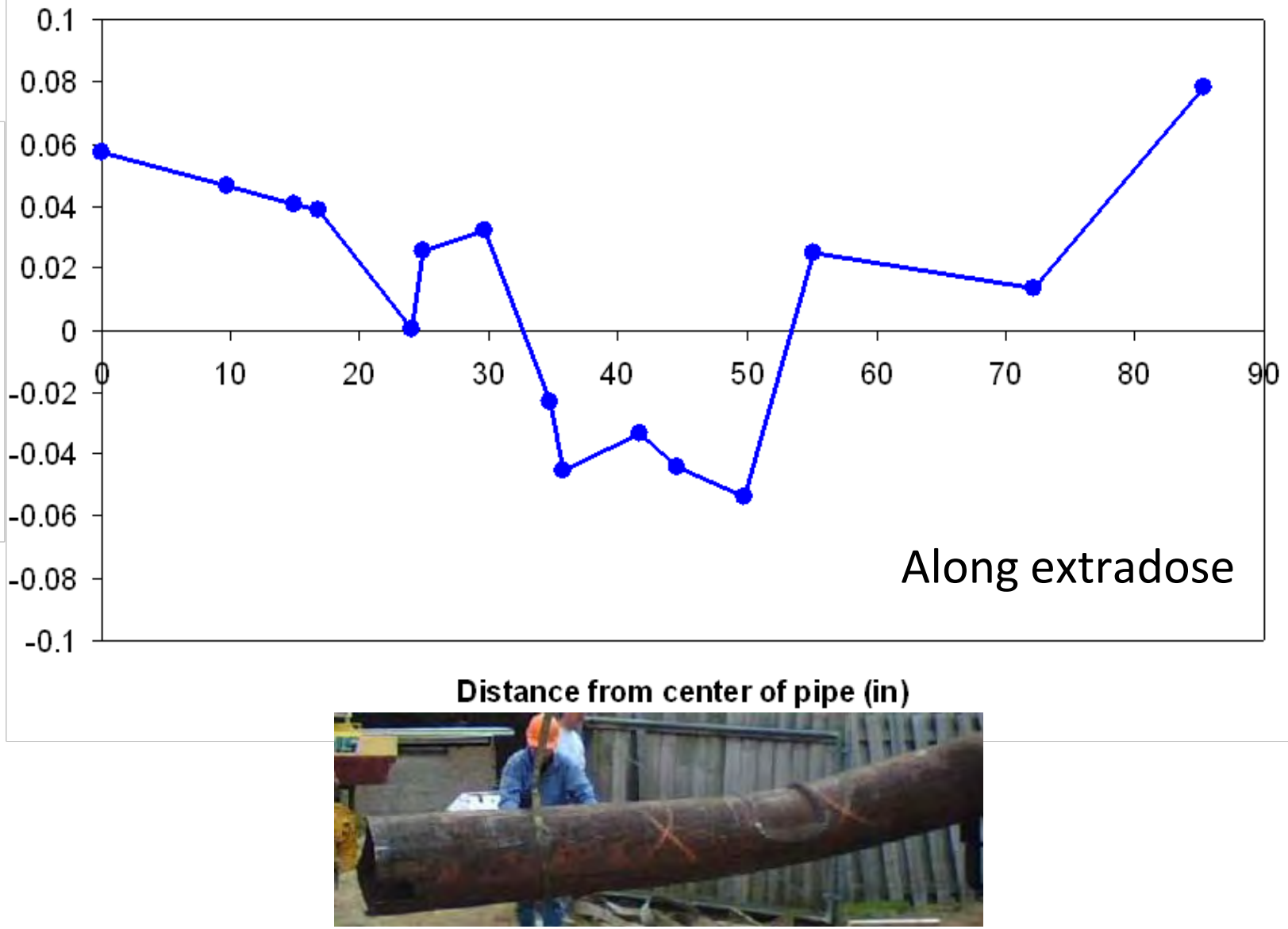
Ultrasonic measurements on NIST Pipe



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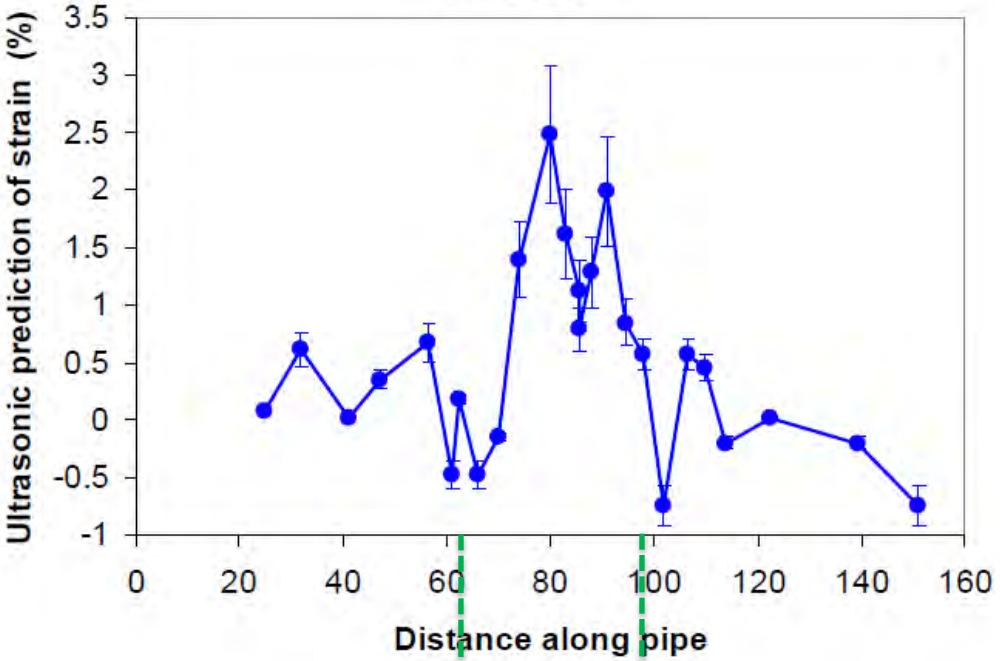
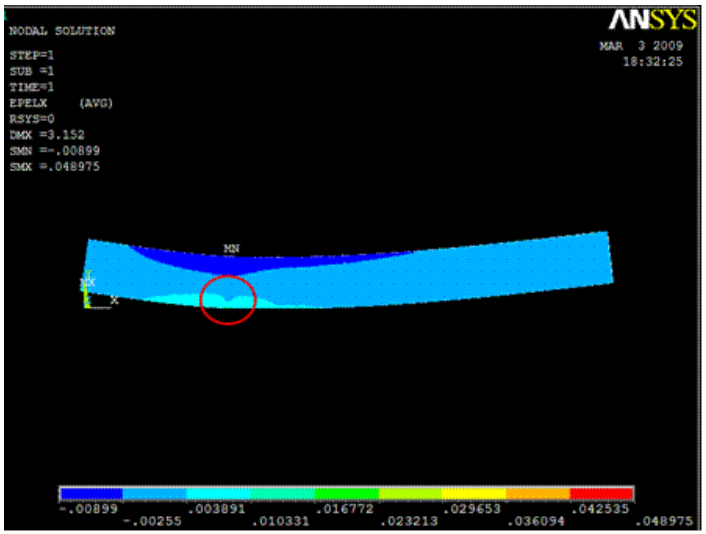
2008 PRCI MD 1-6 and DOT Results
Direct measurement of strain in bent pipe

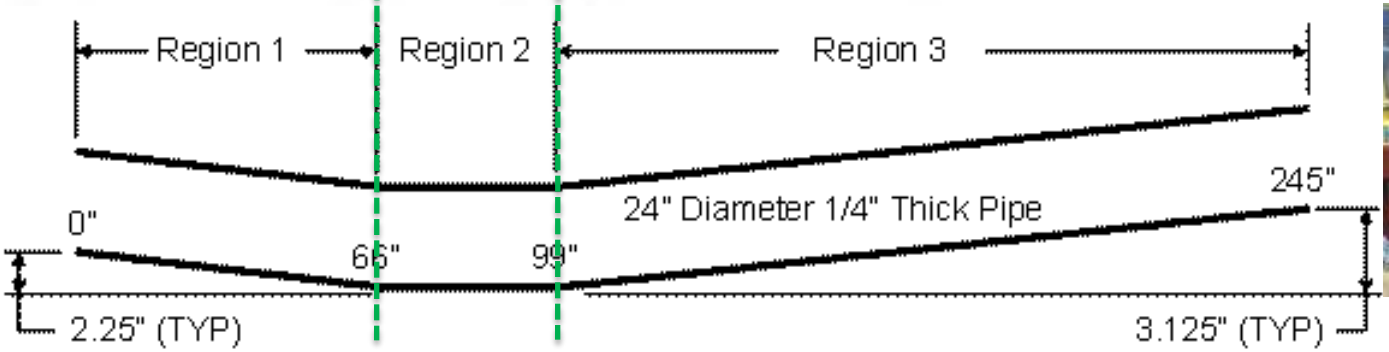
Ultrasonic prediction of strain along extradose of pipe



FEM prediction of strain



FEM Courtesy of Steve Gosselin and Vladimir Korolev



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Field work sites

- In the field pipes are constrained differently than in the lab
- Determine sensitivity in field
- Determine robustness of measurement methods
- Develop field calibration methods
- Southern California Gas
- Looking for sites from East Coast O&G Companies or Utility

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Subsidence and levee crossing

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Catenary spans

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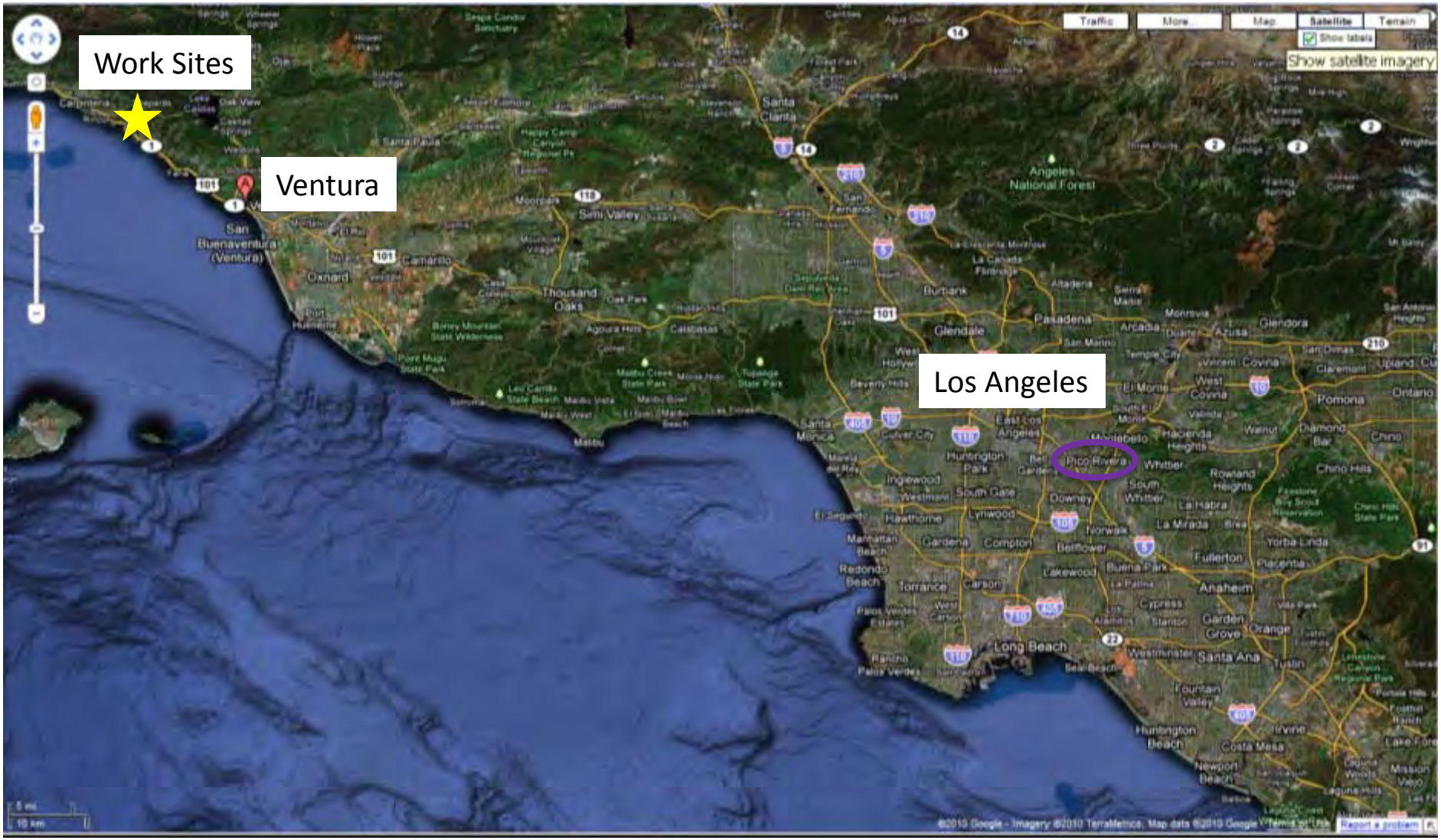
Satellite view



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Big V Worksite

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Little Canyon Worksite

Southern Cal Gas
Field Work Pictures
January 12- 14, 2010
Before the storm

Big V
16” diameter
X 52, 0.344 inch wall

Little Canyon Work Site, 8” diameters X 42

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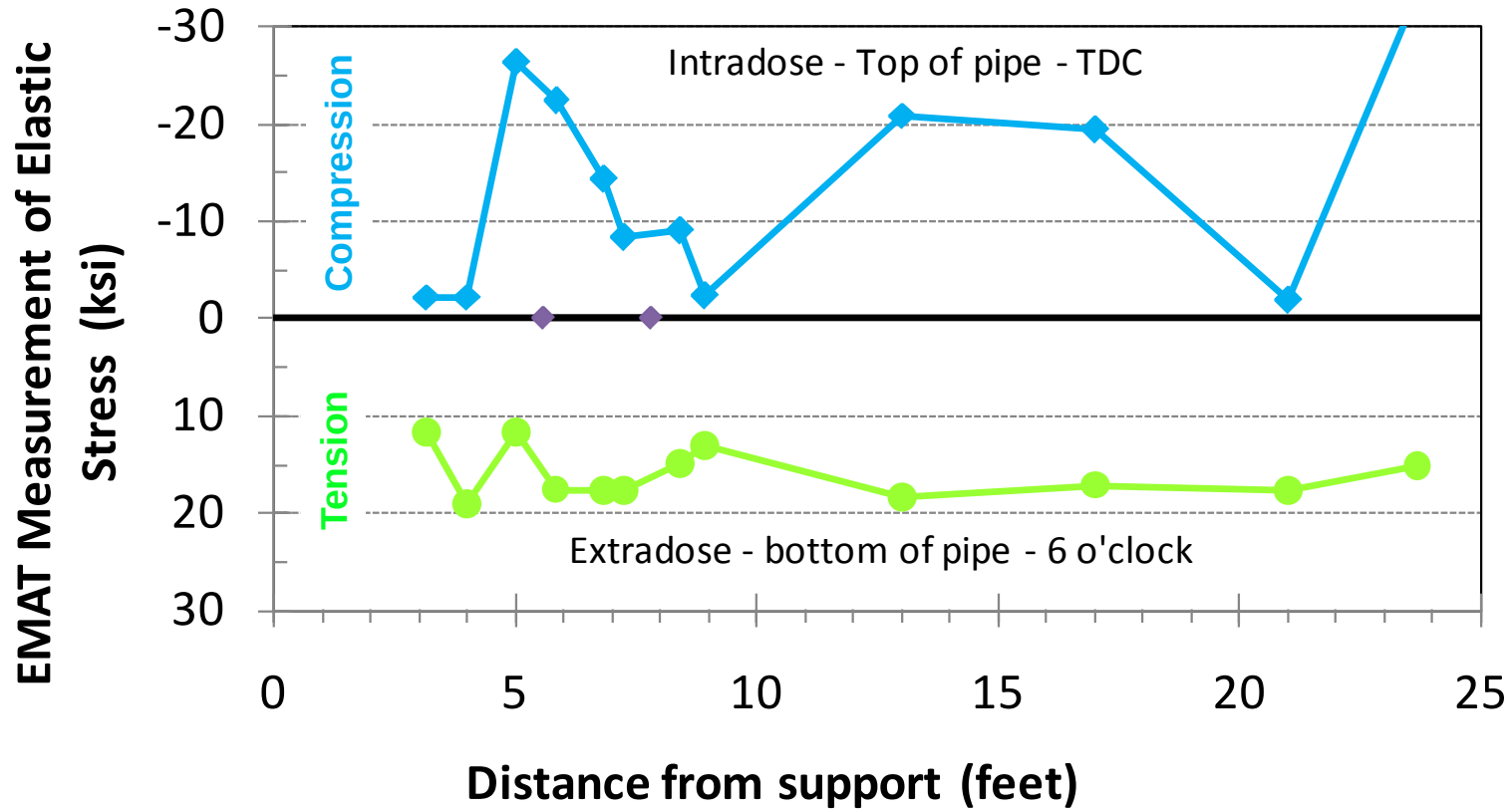
EMAT Measurement of Elastic Stress Along Little Canyon Pipe



Expected stress

-14 ksi

16 ksi

- Ultrasonic stress measurement is in good agreement with expected tensile stress on extradose

- Ultrasonic stress measurement on intradose fluctuates around expected value

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So Cal Gas Pico Rivera, January 15, 2010

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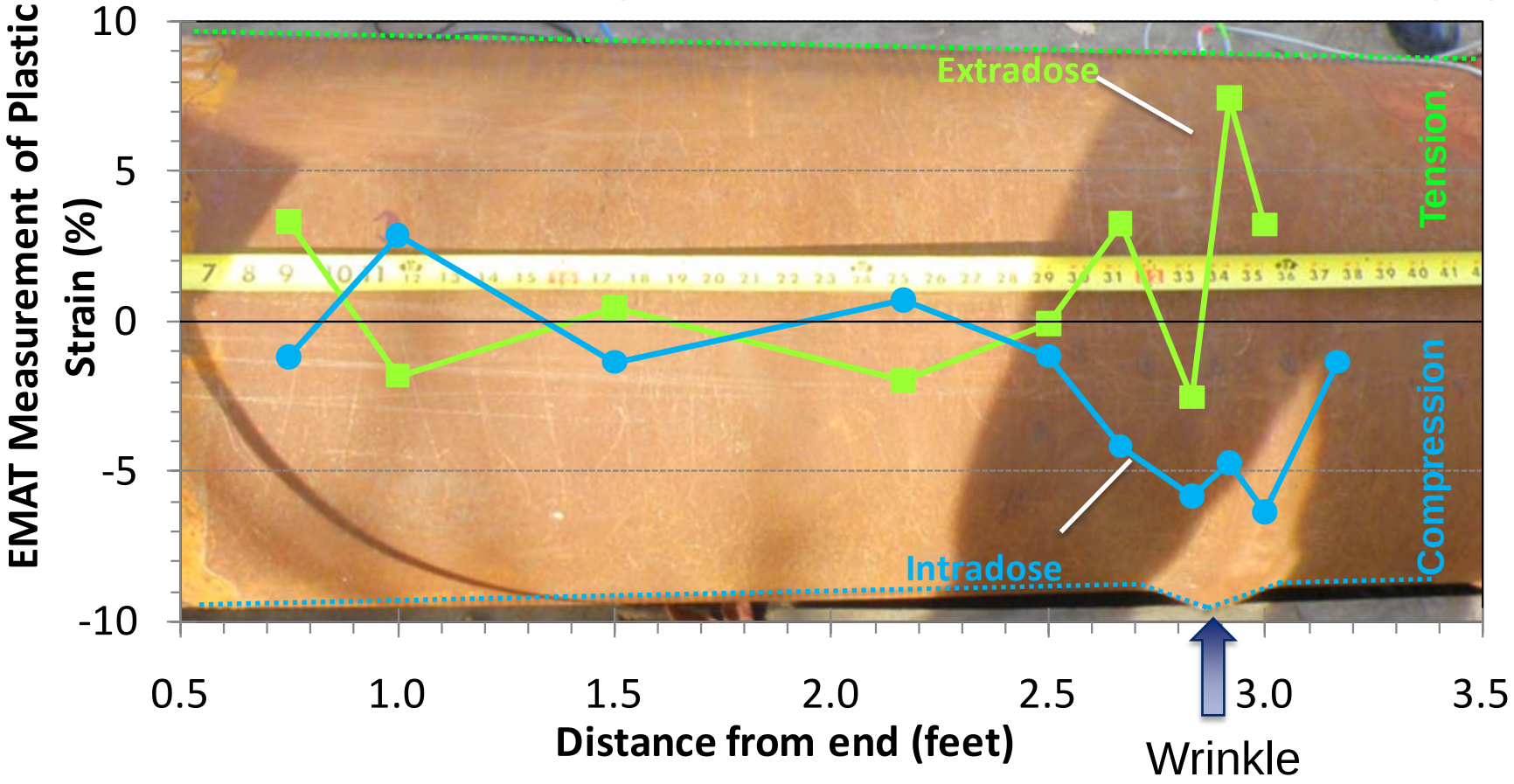
Thank you Siari Sosa

EMAT measurement of plastic strain on Pico Rivera pipe



- Measurements were made along the extradose (top) and intradose (bottom) along the dotted lines
- ~Strain free away from wrinkle
- Near wrinkle
  - Compression on the intradose
  - Generally tension along the extradose

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Dented Pipe Applications

- Previous data on dented pipes from DOE project
- Can revisit data to work towards extracting useful strain and stress levels
- Can measure Queens and GDF dents

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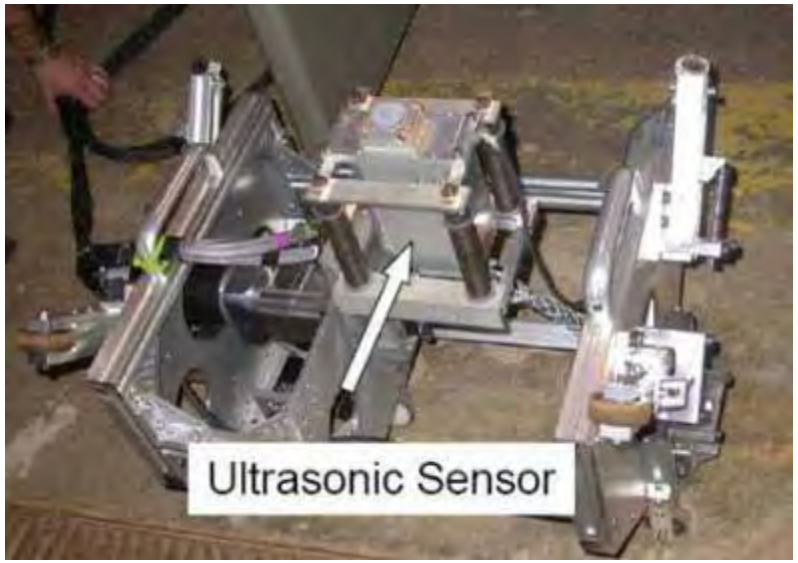
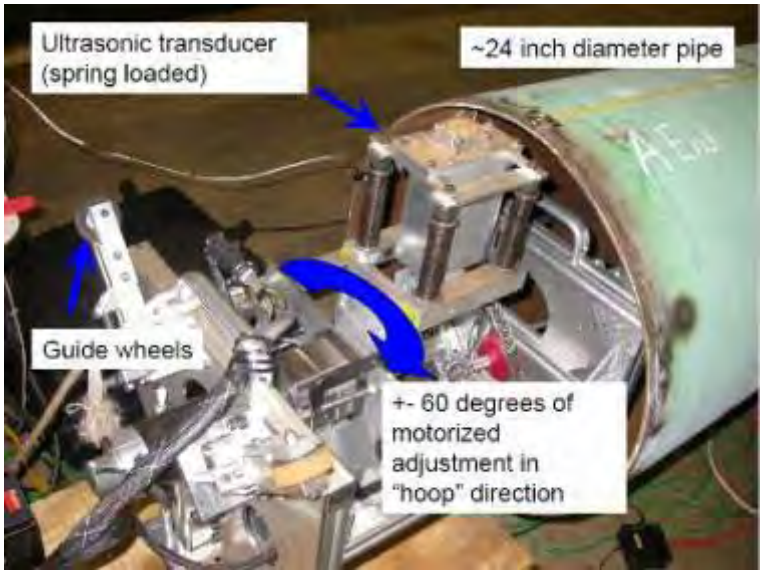
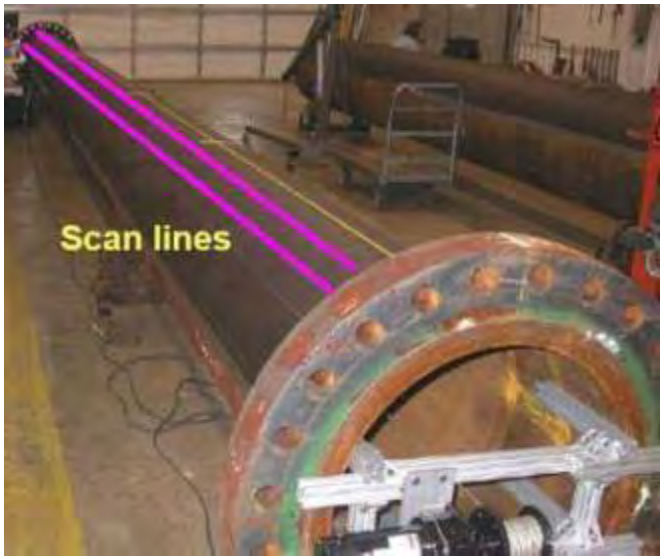
Motorized cart for in-pipe testing 2004 – 2005
DOE/DOT Field Tests at Battelle







- **Focused on ILI applications**
- **Computer controlled**
- **Data every 0.1”**
- **Speeds up to 10 inches per second.**
- **Faster speeds are attainable**

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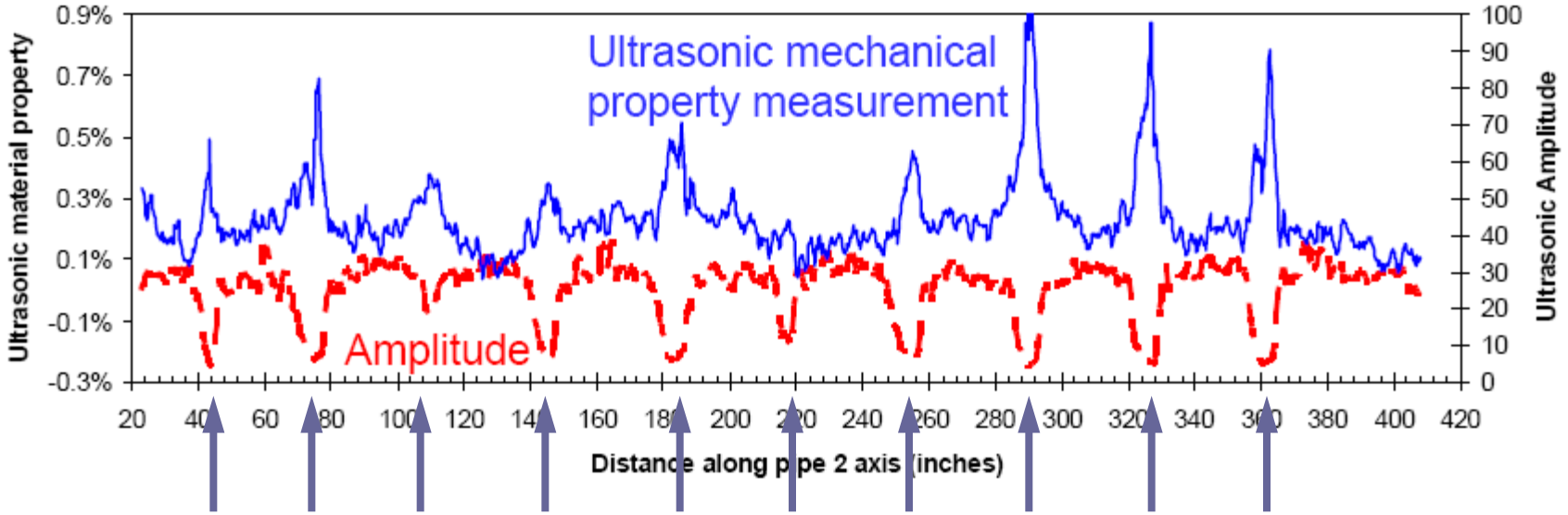
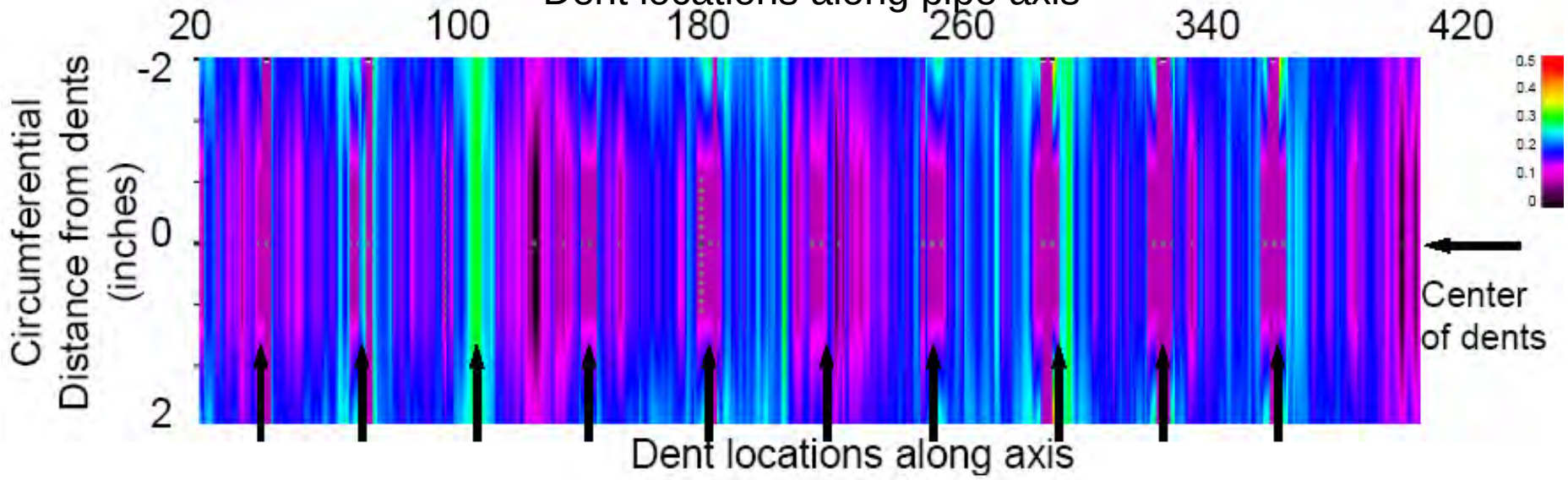
EMAT ranking of dent severity



Dent locations along pipe axis



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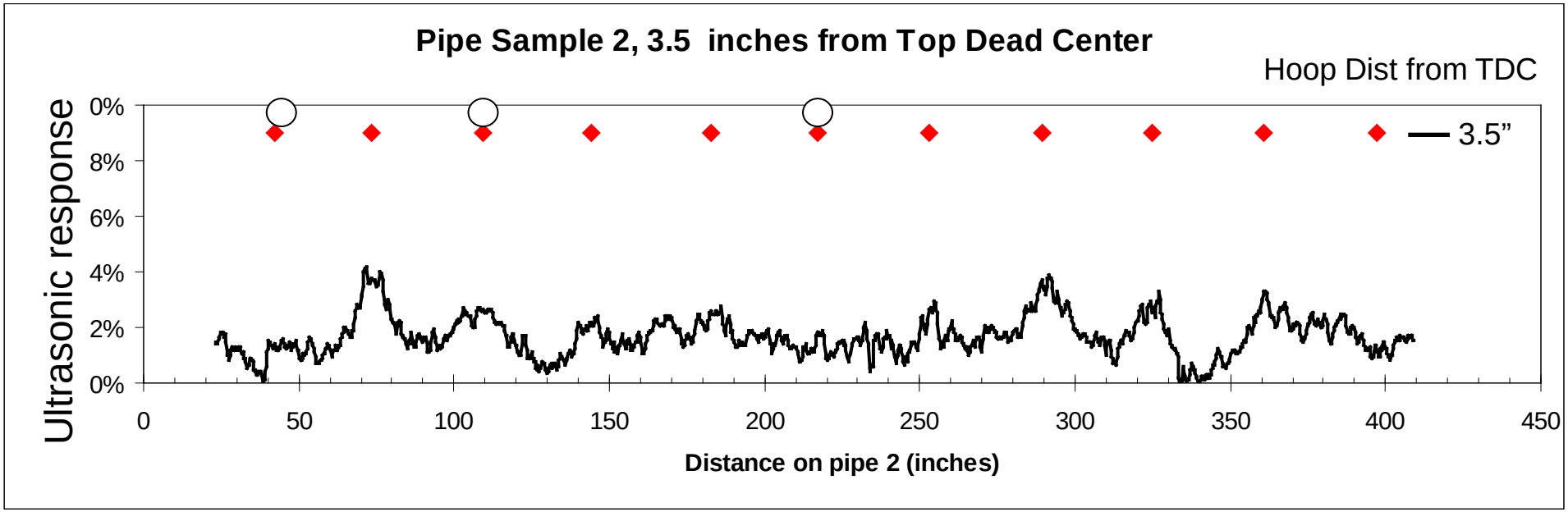
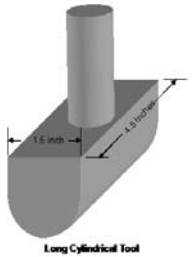
Dented Pipe DOE/DOT work field test Results Pipe 2

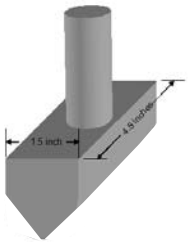


PNNL Ranking	1	2	1	2	3	1	2	3	2.5	3	0
Benchmark	1	2	1	3	2	1	2	3	2	3	0

Blind

Calibration





0 = No dent
1 = Least Severe
2 = Moderate Severity
3 = Most Severe

(1) Spherical (2) Cylindrical (3) V-shaped

Work performed while at Pacific Northwest National Lab

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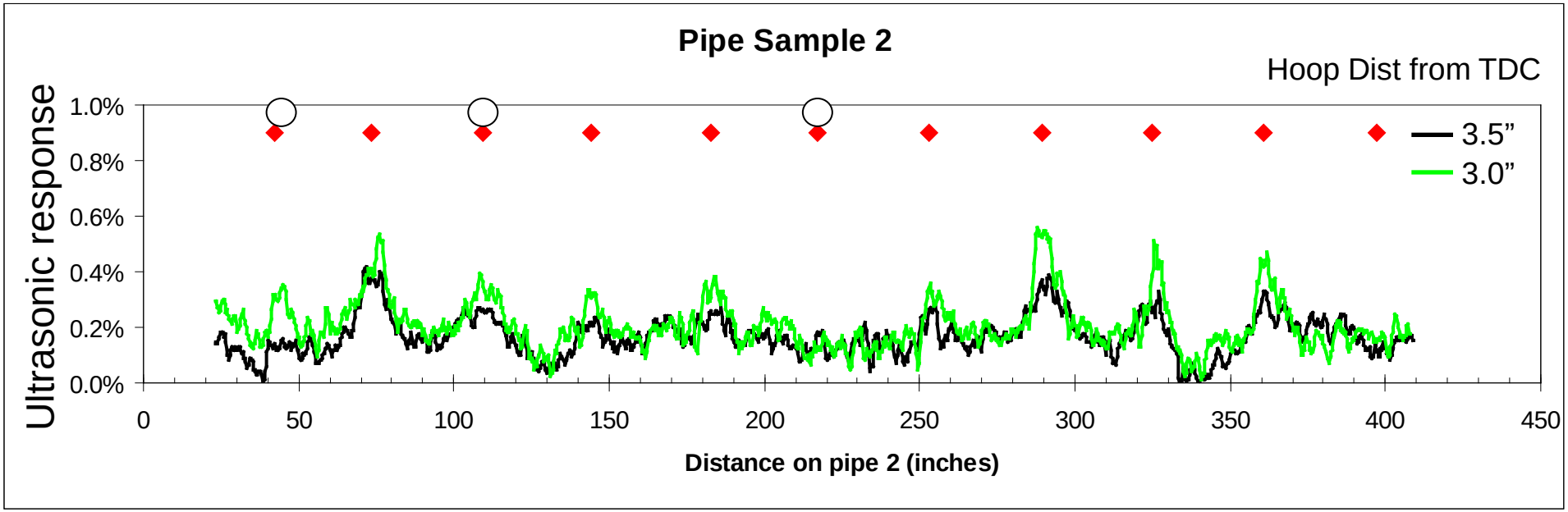
Dented Pipe DOE/DOT work field test Results Pipe 2



PNNL Ranking	1	2	1	2	3	1	2	3	2.5	3	0
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Blind

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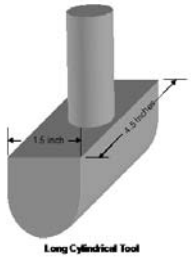

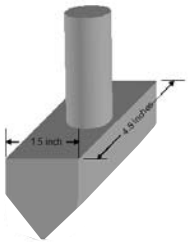

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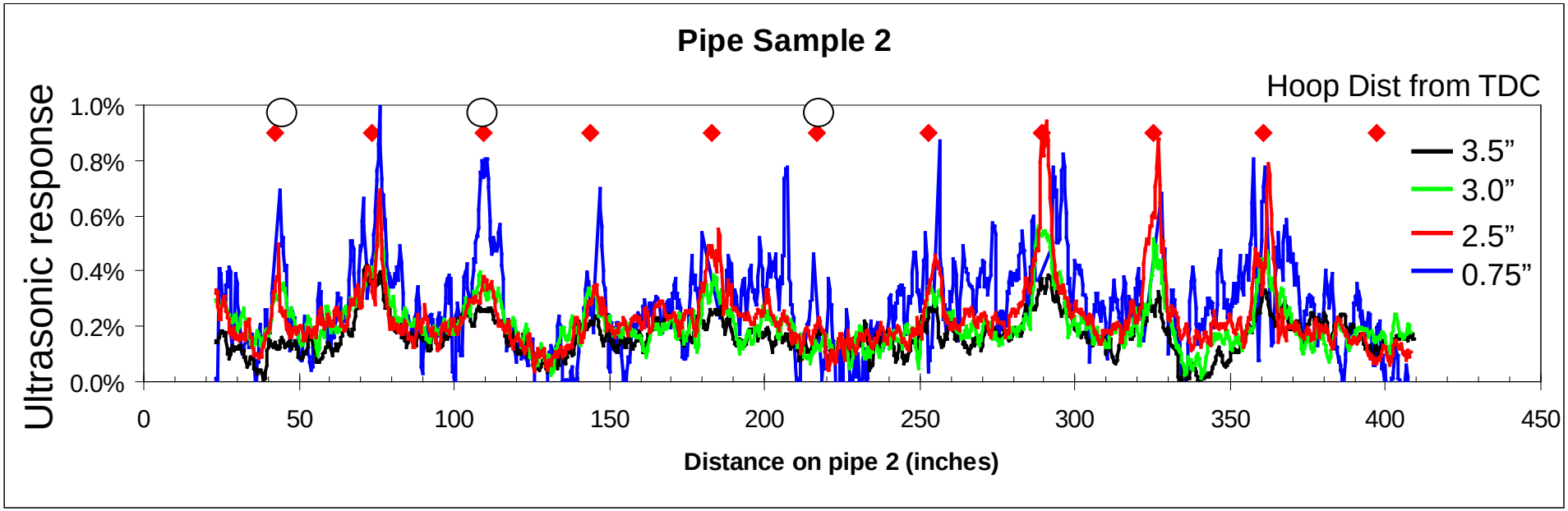

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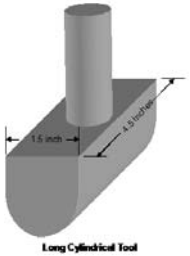

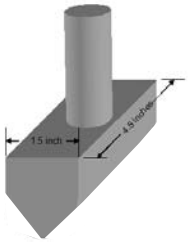

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2 = Moderate Severity
3 = Most Severe

(1) Spherical (2) Cylindrical (3) V-shaped

Work performed while at Pacific Northwest National Lab

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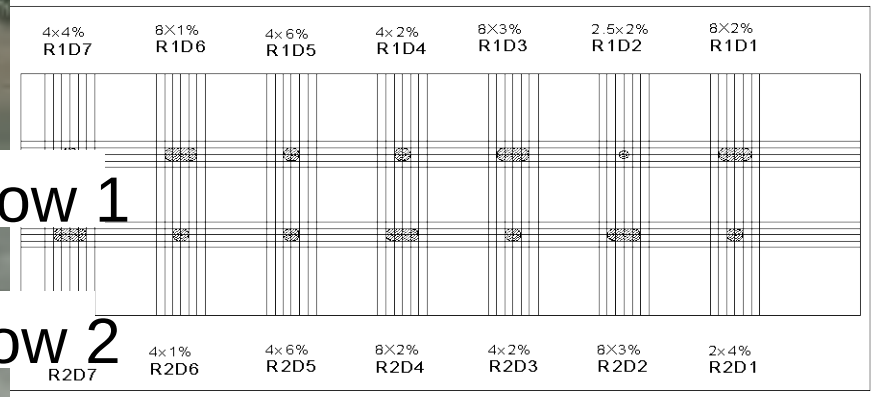
PNNL 24” diameter dented pipe
14 dents in 2 rows

8X2% R1D1 | 2.5x2% R1D2 | 8X3% R1D3 | 4x2% R1D4 | 4x6% R1D5 | 8X1% R1D6 | 4x4% R1D7



2x4% R2D1 | 8X3% R2D2 | 4x2% R2D3 | 8X2% R2D4 | 4x6% R2D5 | 4x1% R2D6 | 8X.5% R2D7

132 inches

285 inches

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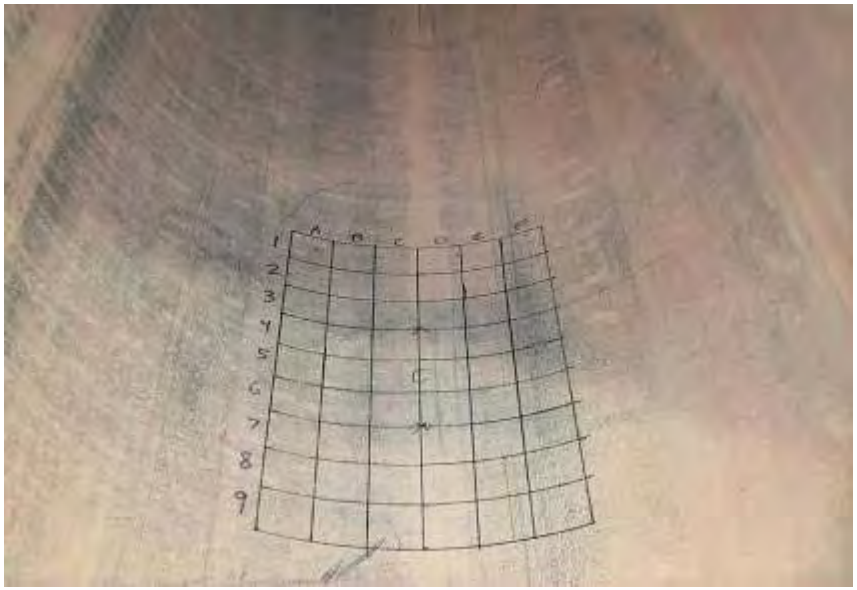
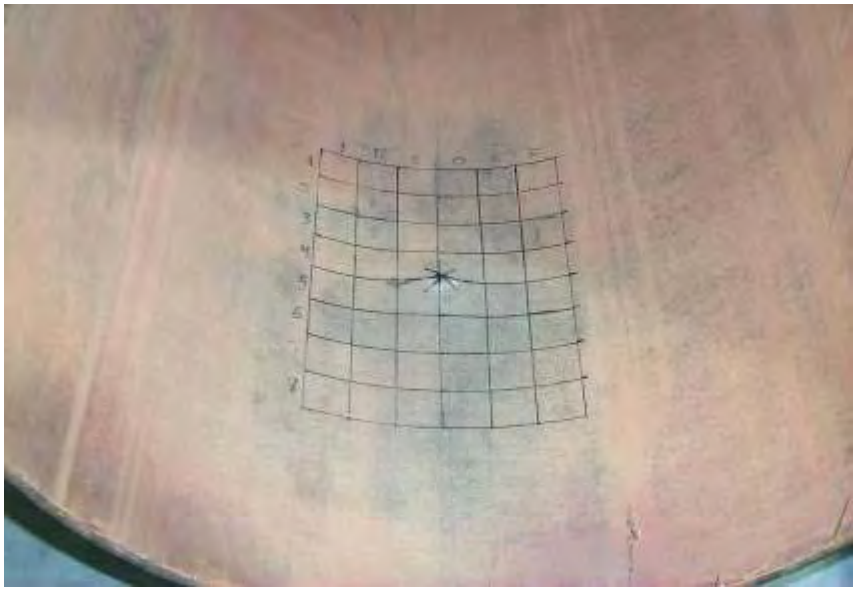
Dent measurement locations

8” indentor, 2% diameter depth



2” indentor, 4% diameter depth



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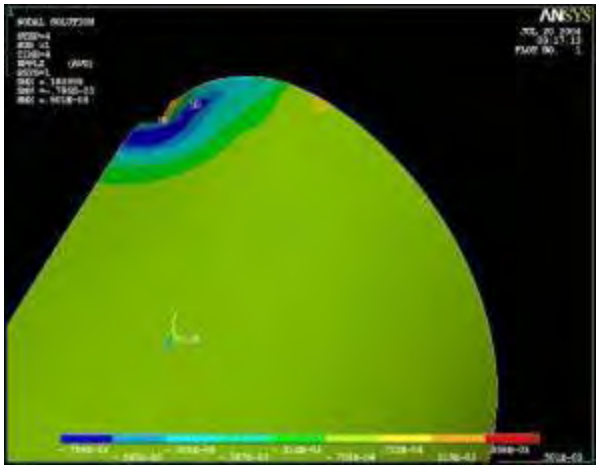
Finite element predictions of stress and strain in dented region

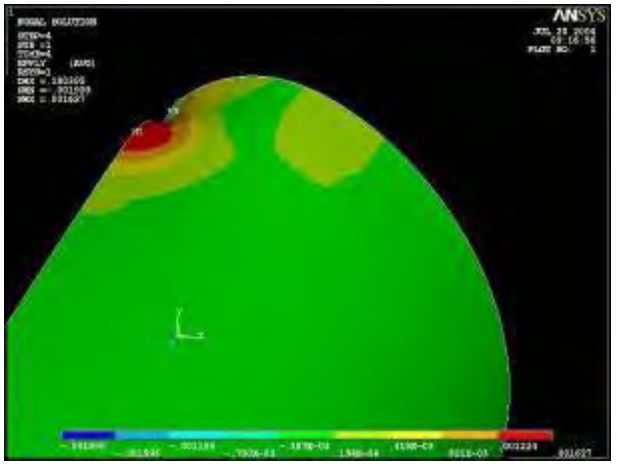
8” indentor, 2% diameter depth

2” indentor, 4% diameter depth

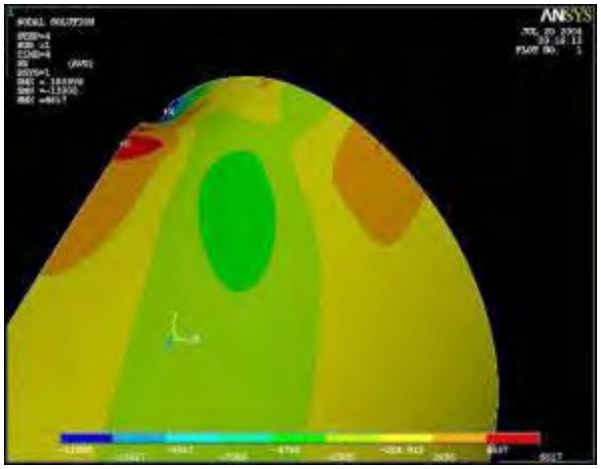
Axial

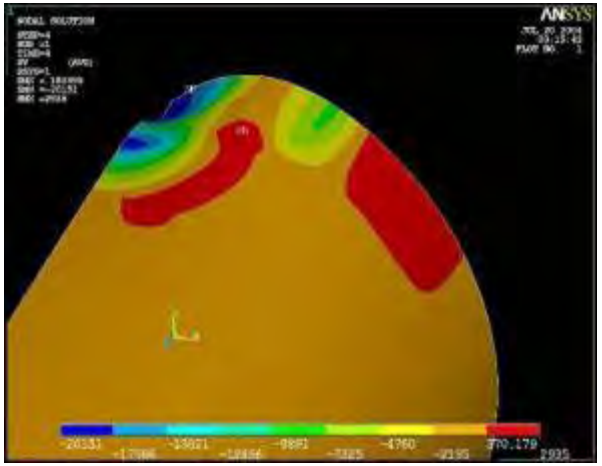
Circumferential





Strain





Stress

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Future directions

- Strain measurement outside pipe
  - Team with instrument provider
- Develop ILI Strain Tool
  - Team with ILI vendors
- Dents
  - Revisit previous data and pipes
  - Develop methods to quantify strain in dents
  - Team with other PRCI/DOT projects
  - Teaming with University of Vermont students on fellowship for neural network computational methods

ILI Tool

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Proposed PRCI ARA Project

Ultrasonic measurements of strains in bent and dented pipelines

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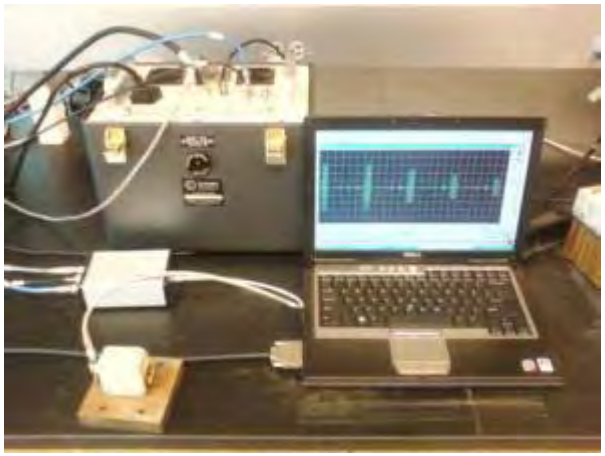
Goal: Battery Powered Tool for Strain Measurement

2000 - 2006



2009 EMAT System

Battery powered, handheld EMAT system from equipment provider March 2010

- Battery powered handheld device will make measurement available for wide range of applications

- Benefit pipeline owners and operators and utility companies with bends, dents, wrinkles, kinks.

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Research Objectives:

1. Field measurements on strained pipes
2. Develop field calibration methods for ultrasonic measurement of strain
3. Integrate strain prediction algorithm into commercially available handheld EMAT instrument.
4. Measure strain or severity of dents

Pipe from El Paso Gas

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Proposed Work Plan

- Testing at on pipe provided by PRCI members.
  - Pipes will include bent pipes from El Paso Gas, NIST
  - Dented pipes from Queens University and Gas de France PRCI Project
- Conduct field tests on pipelines that have been subjected to strains and dented pipes
  - Candidate pipes include suspended pipes and those exposed and bent during previous landslides or by other causes and dented pipes.
- Develop field calibration methods for EMAT measurements of strains and pipe grade
  - Refine methods to calibrate the measurements in the field
  - Develop data base of ultrasonic properties as a function of strain on vintage pipes
- Integrate ultrasonic measurements of strain into commercially available EMAT instrument
  - Handheld commercial EMAT system will be available March 2010
  - We are developing partner agreement with EMAT manufacturer

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Summary

- Back on track with project plan after move to ARA
- Data on bent pipe from NIST and wrinkled pipe from El Paso Gas
- Completed first set of field work at Southern California Gas
  - Catenary
  - Suspended pipe
  - Wrinkled pipe
- Good results on wrinkled pipes and suspended pipes
- Proposed follow on work to PRCI for 2011
- Partnering with EMAT equipment provider to produce handheld prototype battery powered strain measurement tool – 2 years
- Looking for “local” field work sites to conserve resources
- Looking for pipes

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Back up slides

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Bulged pipe from field (~ 40 years old X60), 2005

- Bulge detected with ILI caliper tool
- Bulge may have occurred during hydrotest
- Removed from service to determine:
  - Mechanical properties
  - Burst pressure

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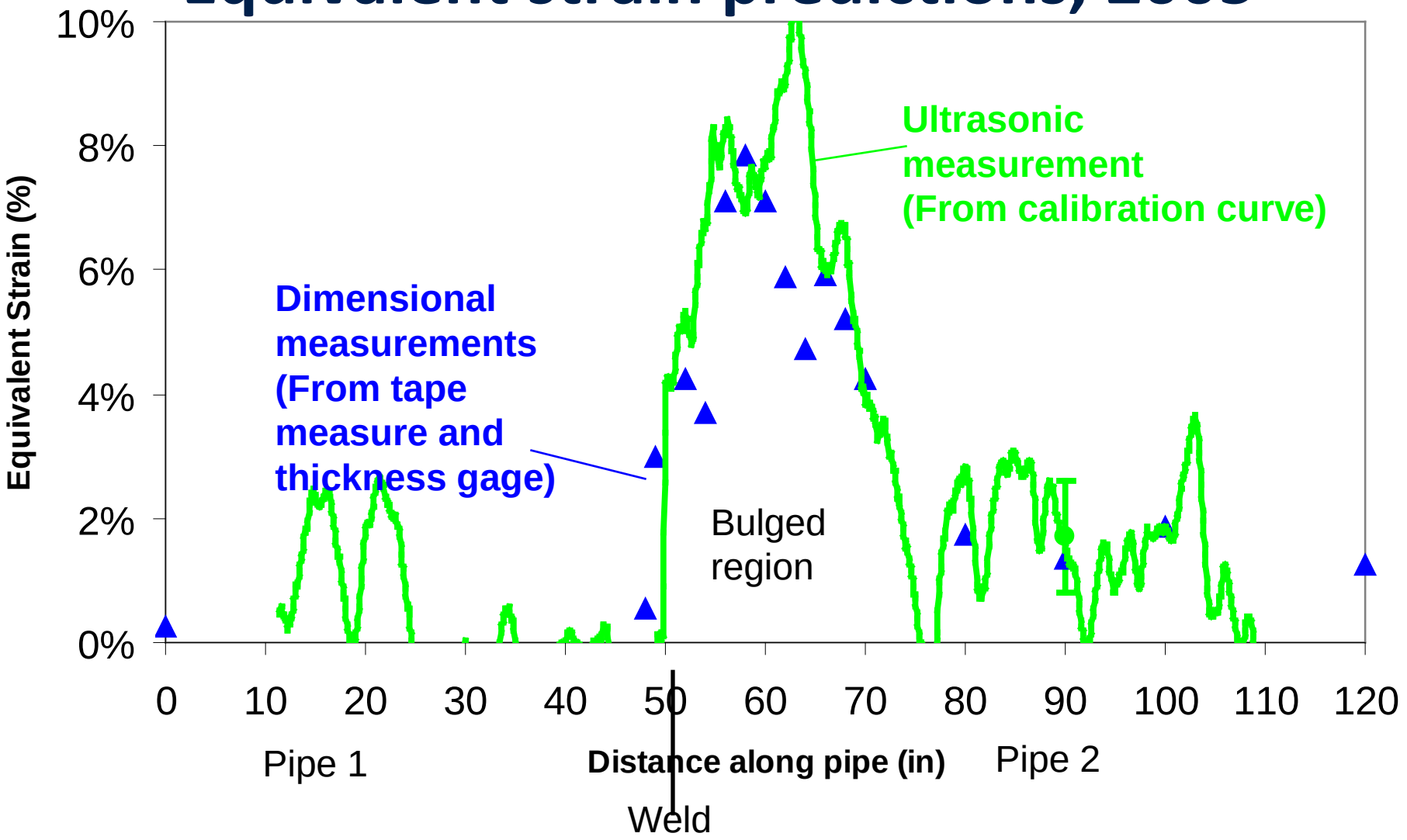
Equivalent strain predictions, 2005



Excellent agreement with direct dimensional measurements for strains above ~1.5%

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Fault crossing pipe replacement

- Utility company is replacing straight pipeline across fault line in Northern California with bent sections.
- We measured pipe before and after field bending.
- Realistic in-field conditions
- **Unique baseline data for assessing the integrity after future earthquakes.**

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Fault Crossing Worksite

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Utility staff and inspection company representative look over our work at PG&E Fault Crossing

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EMAT scanner and equipment

- On the fly data collection grounding fix
- 2 weeks on site
- Transducer tracking
- Cold mornings (45 degrees F)
- Hot days (95 degrees F)
- Generator powered

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EMAT measurements along pipe

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Fixing equipment…again…

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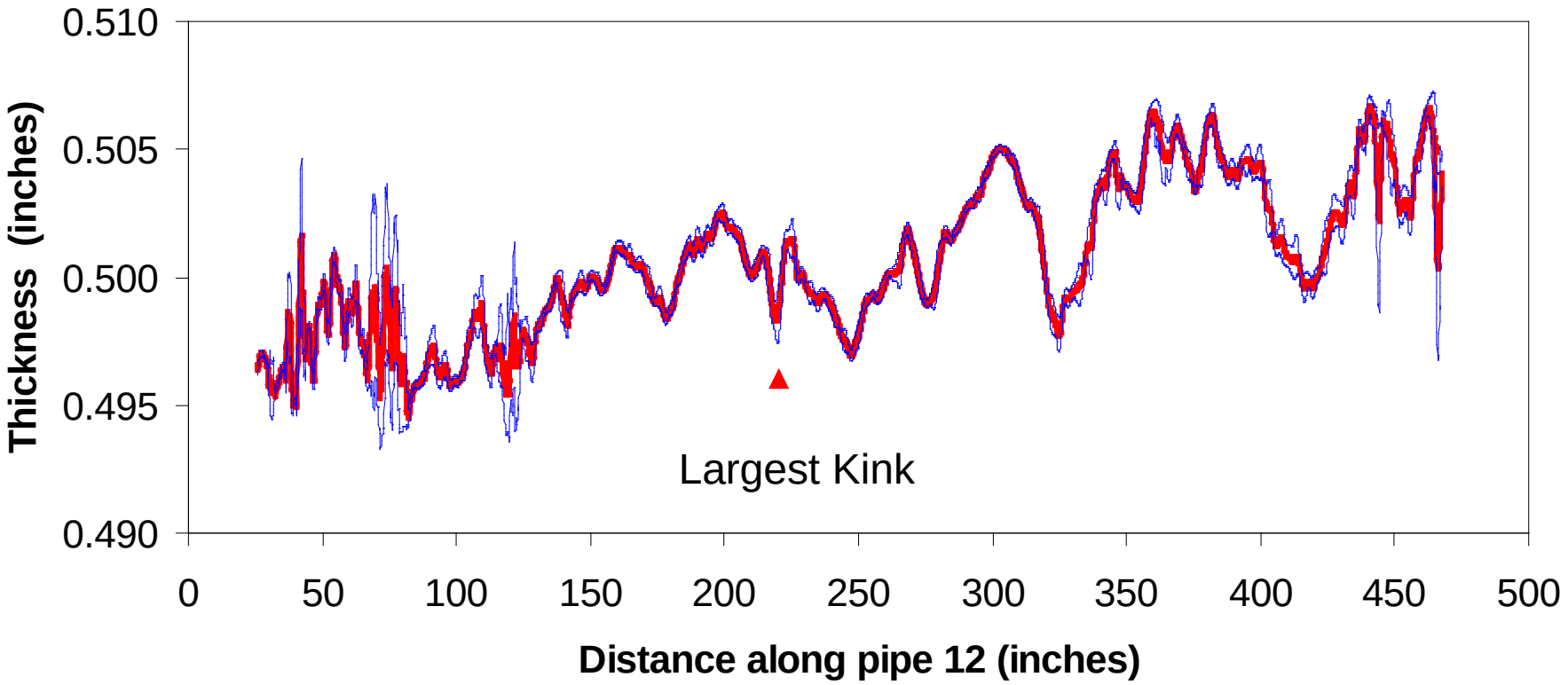
Thickness variations in Pipe 12 (before bending)



- Less than 0.5% variation in time of flight along 40 feet of pipe
- outside in the dirt running off a generator

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Various views of bent pipes

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Setting up to scan bent pipe

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Packed and ready to go to the field!

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Bending contractor kinked the pipe

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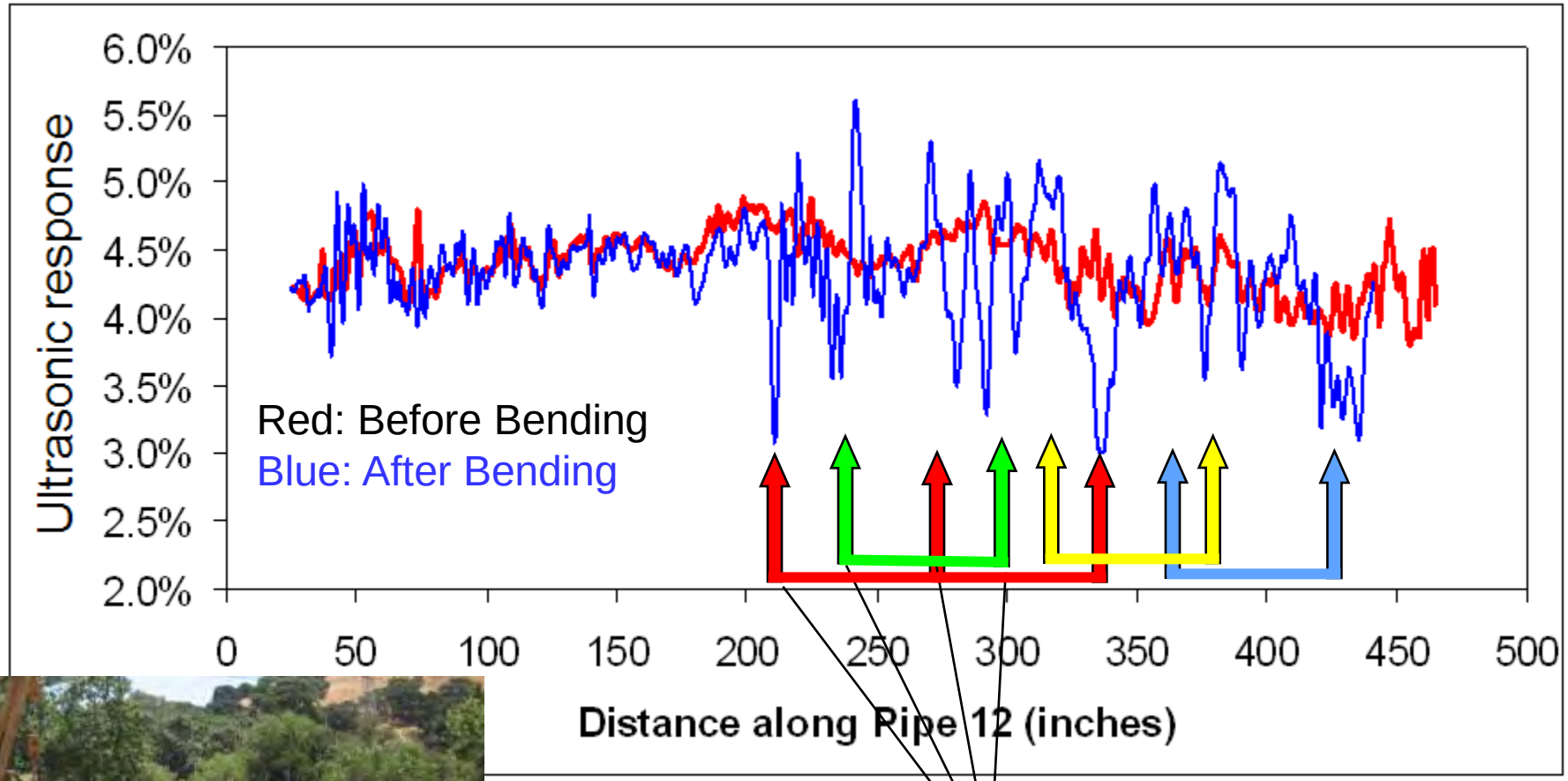
Kinked Pipe #12, 270 degrees (Intra dose)



Visible kinks

Pipe was kinked on each side of mandrel
Colored arrows = length of mandrel

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A good end to a busy and productive 2 weeks

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