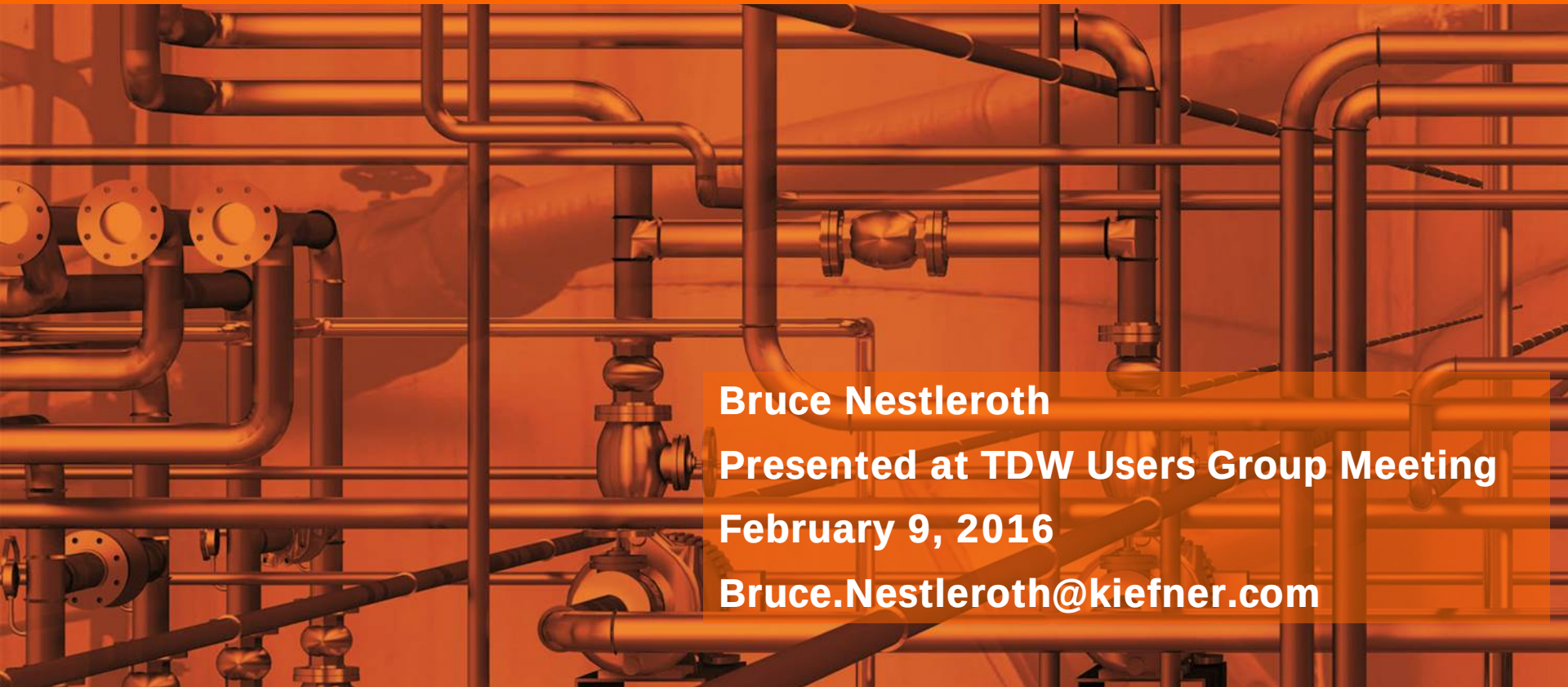
Improve and Develop ILI Tools to Locate, Size, and Quantify Complex/Interacting Metal Loss Features

Kiefner



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Presented at TDW Users Group Meeting

February 9, 2016

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Safety first,
Safety always

Health and Safety of people is our number one priority.

Alarms

Emergency exits

Emergency numbers

Gathering point

DTPH56-13-T-000009
Improve and Develop ILI Tools to Locate, Size, and Quantify Complex/Interacting Metal Loss Features

Three challenges for in-line inspection (ILI) integrity assessment of metal loss defects involve interacting defects:

1. Denting and metal loss: Corrosion metal loss in a dent is usually not very severe, where metal loss caused by gouging can be very severe.
2. Corrosion on the seam: Modern ILI tools need to differentiate between crack-like selective seam weld corrosion (SSWC) from conventional corrosion that just happens to encounter a low frequency ERW seam
3. Wide area corrosion (pits in patches): Some of the pits within a large corrosion area may not be detected or sized, and failing to include these defects may underestimate the amount of missing metal when attempting to calculate a failure pressure

This project developed methodology and algorithms to improve characterization of complex features

Project history
DTPH56-13-T-000009

- Kiefner Prime contractor
  - TD Williamson Subcontractor
- Proposed to DOT PHMSA in 2012
- Project start September 1, 2013
- 9th contract awarded that year
- Technical work complete, in the reporting phase

Approach

- Five different ILI measurements made on a MDS tool were used to develop the discrimination algorithms:
  - Conventional axial MFL technology (high field)
  - ID versus OD discrimination sensors
  - Deformation measurements
  - Spiral MFL technology
  - Reduced field axial MFL measurements (low field)
- The advantage of using data from a single tool run is to avoid the additional step of aligning the data between runs.

Components of MDS tool

Spiral MFL, Standard High Resolution MFL, deformation and Low field MFL

Excavations

- Data from actual pipeline anomalies collected at excavation sites was a key part in this development.
- Thanks you to the pipeline companies provided access to excavation sites
  - Koch
  - Shell
  - P66
  - ConocoPhillips
- ApplusRTD technicians performed special in ditch measurements

Improve ILI Quantification of Corrosion on the Long Seam

Goal

- Provide a means to meet the requirement: 49 CFR §195.452 (h)(4)(iii)(H)
- "(h) *What actions must an operator take to address integrity issues?* — (1) *General requirements.* An operator must take prompt action to address all anomalous conditions the operator discovers through the integrity assessment or information analysis. In addressing all conditions, an operator must evaluate all anomalous conditions and remediate those that could reduce a pipeline's integrity. An operator must be able to demonstrate that the remediation of the condition will ensure the condition is unlikely to pose a threat to the long-term integrity of the pipeline. An operator must comply with §195.422 when making a repair. (4) *Special requirements for scheduling remediation* *(iii) 180-day conditions.* Except for conditions listed in paragraph (h)(4)(i) or (ii) of this section, an operator must schedule evaluation and remediation of the following within 180 days of discovery of the condition:

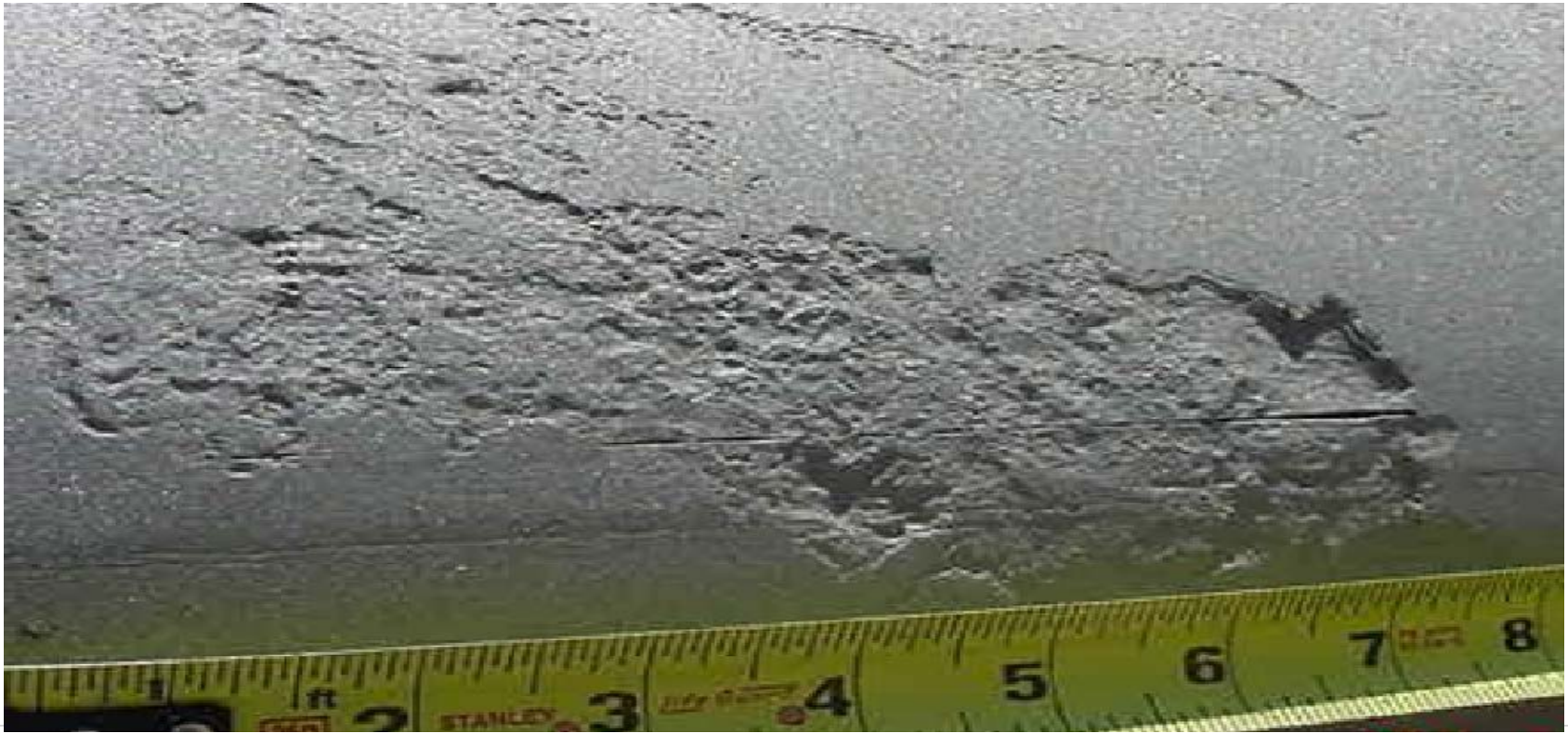
(H) *Corrosion of or along a longitudinal seam weld.*"

Selective Seam Weld Corrosion is a major focus of this Regulation

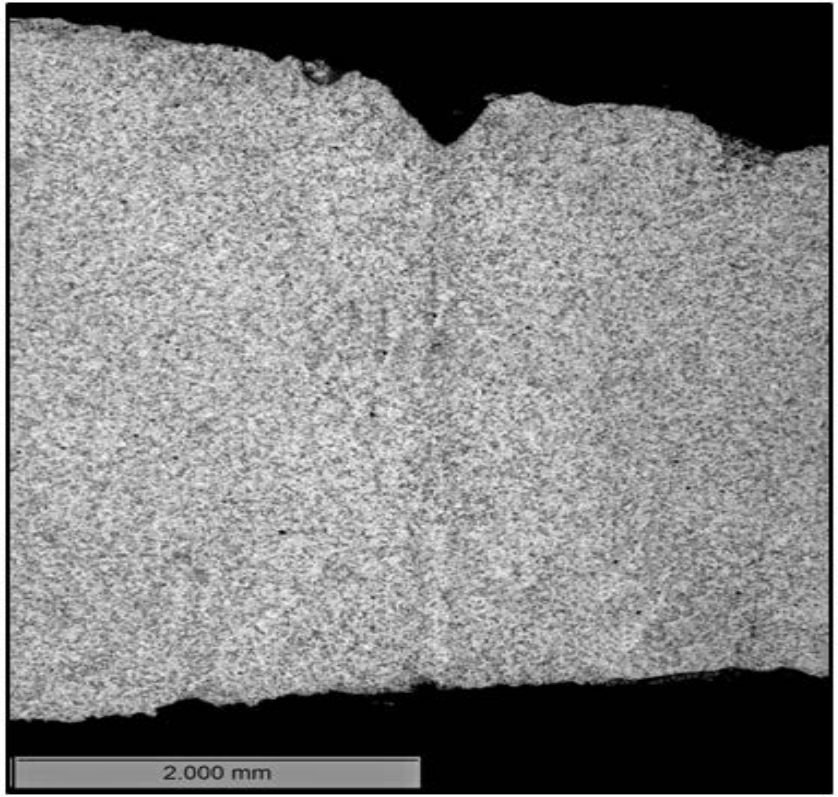
- Selective Seam Corrosion (SSWC) is:
  - Corrosion that preferentially attacks the bondline of ERW or FW seams. The surrounding pipe surfaces usually exhibit relatively shallow corrosion.
- SSWC is a relatively rare time dependent defect but warrants special attention:
  - Difficult to detect with conventional MFL corrosion detection tools;
  - Corrosion by itself not good indicator;
  - Increases the tendency to fail by rupture;
  - Low stress ruptures have occurred.

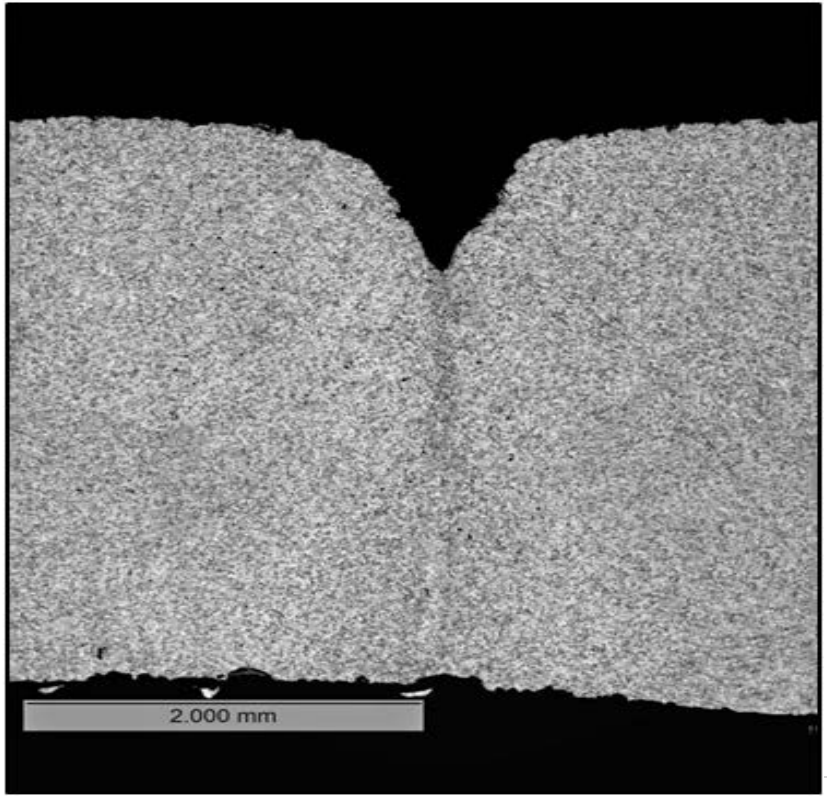
Selective Seam Weld Corrosion

Selective Seam Weld Corrosion



Selective Seam Weld Corrosion





Approach to §195.452 (h)(4)(iii)(H)

- Develop a conservative procedure to evaluate the pipeline in advance of excavation for <u>all potentially injurious anomalies resulting from seam associated corrosion</u> using the most recent technology supported by laboratory research and field metallurgical data specific to each pipeline.
- Conservatively excavate and repair all identified potentially injurious anomalies.

Dig 13-1617

ILI Call:

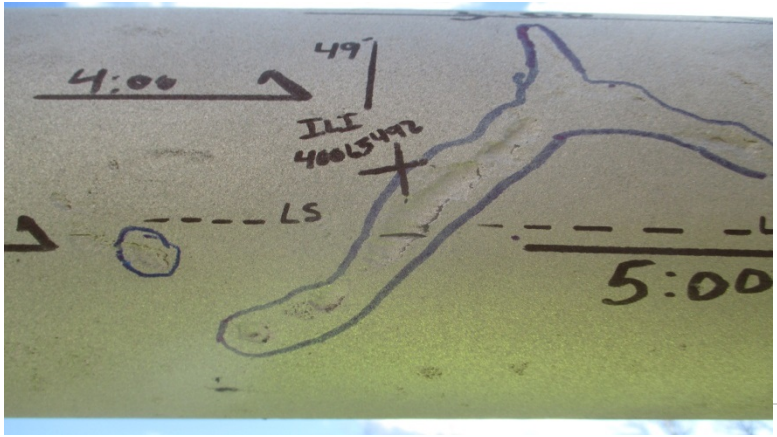
- 2 defects nearby, one with Strong SMFL Signal

Observation:

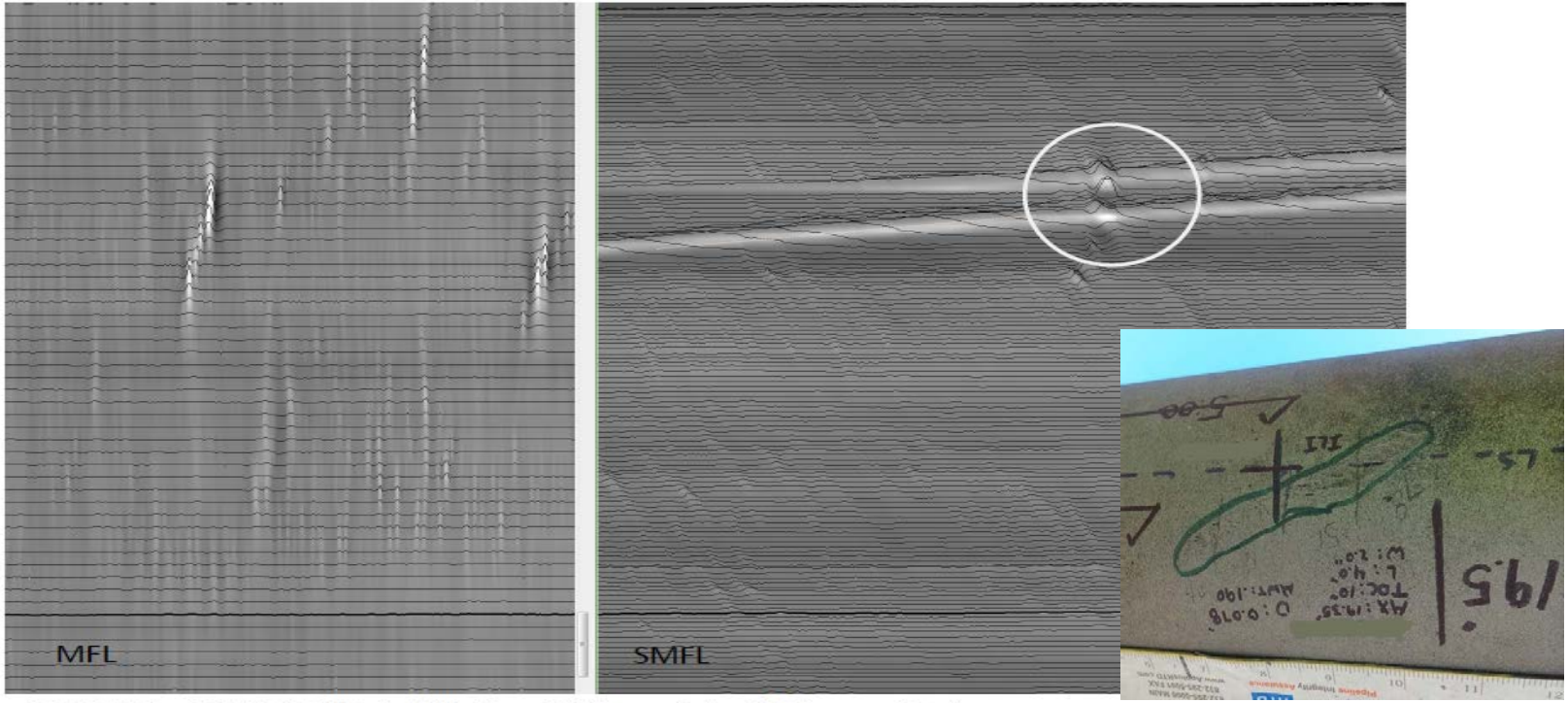
- Shallow corrosion .
- Short selective seam corrosion.

Action

- Pipe removed in 2014 and shipped to Kiefner for further evaluation



Signals from MDS tool
Dig 13-1617



40065422 – LSW highlighted (lighter LSW possible slight over trim)
Magnetizer Helix overlap, signal duplicates

In the ditch measures: Selective Seam Corrosion

- Groove replication
- Weld seam susceptibility test
- Chemical analysis of the seam weld using x-ray Fluorescence
- Field metallography
- Metal loss depth determination

Algorithm for Identification of SSWC

- The SSWC detection algorithm must
  - Detect all SSWC anomalies

  while
  - Dismissing as many corrosion anomalies near the long seam as possible to ensure all SSWC are detected
- Implemented a SSWC identification model that mirrors the evaluation process used by subject matter experts
- Key attributes of the MFL and SMFL signatures are measured in analysis software
- Identification model accepts these measurements and produces a likelihood that candidate feature is SSWC

Signal Features

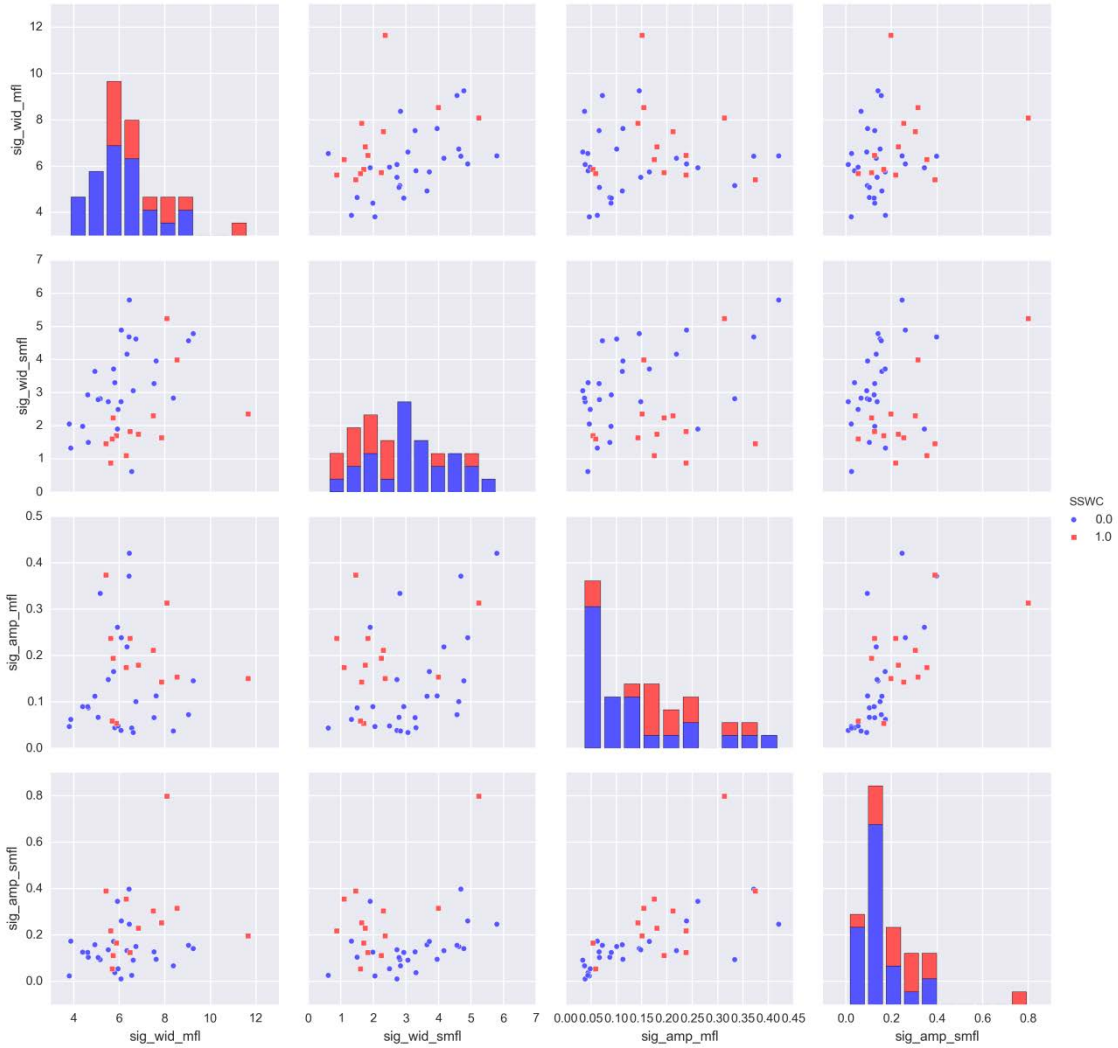
- Data from axial and spiral MFL used
  - Designated *mfl* and *smfl*
- Features used in the algorithm are
  - Width $\mathbb{w}$
  - Amplitude $\mathbb{A}$
- To make the model more general, the raw signal measurements were first nondimensionalized

$$\mathbb{w}_{smfl} = \frac{w_{smfl}}{t} \qquad \mathbb{A}_{smfl} = \frac{A_{smfl}}{B_{smfl}}$$

$$\mathbb{w}_{mfl} = \frac{w_{mfl}}{t} \qquad \mathbb{A}_{mfl} = \frac{A_{mfl}}{B_{mfl}}$$

Feature Pair Plot

- RED – SSWC
- Blue - Corrosion



Algorithm

- $F(z)$ represents the likelihood that a particular anomaly is SSWC.

$$F(z) = \frac{1}{1 + e^{-z}}$$

$$z = \beta_0 + \beta_1 \mathbb{W}_{mfl} + \beta_2 \mathbb{W}_{smfl} + \beta_3 \mathbb{A}_{mfl} + \beta_4 \mathbb{A}_{smfl}$$

- Best fit model coefficients are
  - β_0=-5.21, β_1 =1.08, β_2 =-1.90, β_3 =5.42, β_4 =9.10)

Task 3: Comparing SSWC Measurements To Preliminary ILI Analysis

Dig	TDW #	SSWC Called SSWC	SSWC Called Corrosion	Corrosion called Corrosion	SSWC Length (Inch)	SSWC Depth (%)	Grooving Ratio
13. 1605	40000500		1		0.7	26.6	1.3
	40000503	1			1.7	25.5	1.4
	40000512			1			
13. 1606	40013090	1			2.8	38.3	1.3
	40013056			1			
	40013057			1			
13.1611	40031011&12		1		2.5	15.3	1.2 & 1.4
	40031015	1			1.0	22.7	1.3
	40031031			1			1.3
	40031035			1			1.5
13.1617	40065422	1			0.4	38.3	1.3
	40065424			1			
	40065492	1			0.6	47.3	1.6
	40065506			1			
	40065507			1			
	40065532-35			1			

Dig	TDW #	SSWC Called SSWC	SSWC Called Corrosion	Corrosion called Corrosion	SSWC Length (Inch)	SSWC Depth (%)	Grooving Ratio
13.1630	40301147	1			1.0	35.5	1.2
	40301164	1			2.0	39.9	1.6
	40301165			1			
	40301169			1			
	40301174-5		1		3.0 (gap)	21.0	1.2
	40301180						
	40301191						
	40301198	1			1.5	35.6	1.3
13. 1631	40304840	1			3.0	41.4	1.4
	40304842	1			0.5	23.4	1.3

Results of comparison of SSWC Measurements To Algorithm

	SSWC Called SSWC	SSWC Called Corrosion	Corrosion called Corrosion
Calls	10	3	11
Calls Possible	13	13	11
Percent Correct	77%	23%	100%

Note: When SSWC was called corrosion, a SSWC anomaly was called on that joint

- 13-1605 : 1.7 inch long SSWC found but 0.5 inch long missed
- 13-1611: 22% deep SSWC found but 15% deep missed
- 13-1630: A 35% and a 39% deep SSWC found but 22% with a grooving ratio of 1.2 was missed

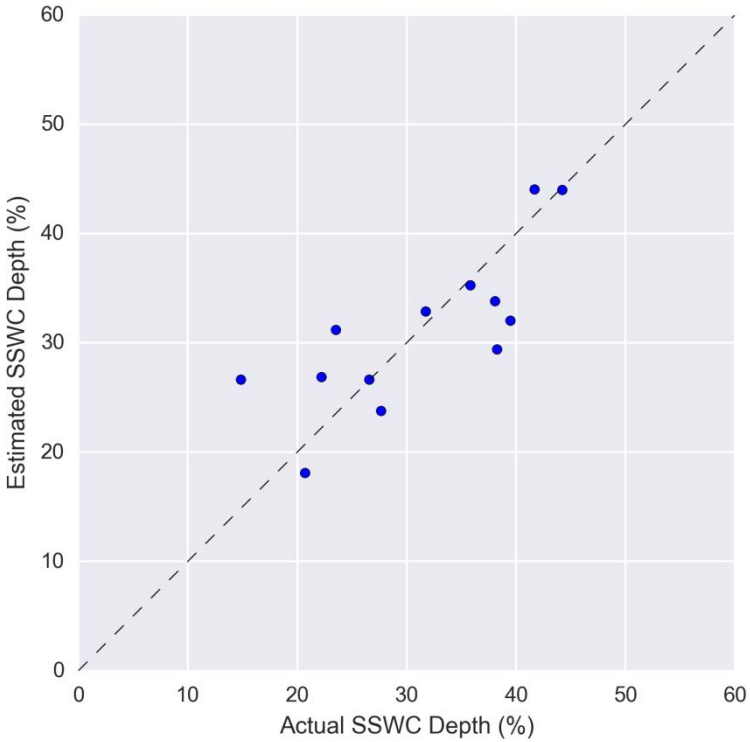
Depth and Length Model

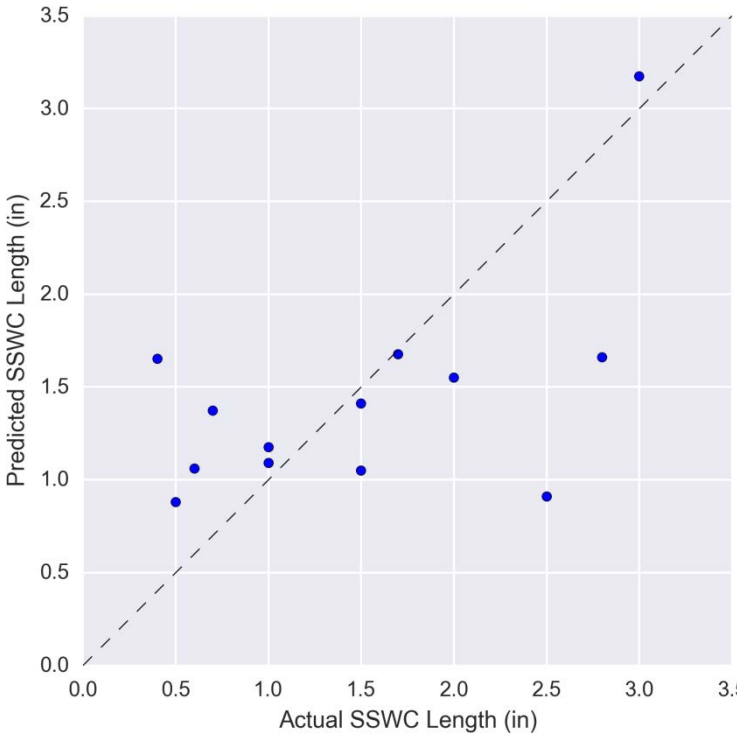
- The depth of the SSWC is combination of the depths obtained from the independent application of the SMFL sizing and MFL sizing models

$$\hat{d}_{sswc} = 0.68\,\hat{d}_{smfl} + 0.27\hat{d}_{mfl}$$

- The length of the SSWC was attempted but was not successful as it provided a measure of the all the corrosion

Unity plots for
Depth and Length prediction





Burst testing of Selective Seam Weld Corrosion (SSWC)

- Six MDS tool identified indications of SSWC were cut out
- The smallest detected SSWC flaw was burst tested.
  - That pipe failed at a pressure of 3,340 psig
  - Did not fail in the seam.
  - This pressure exceeded that required to reach the pipe flow stress as calculated by (YS+UTS)/2 of 3,259 psig.
- Therefore Kiefner concluded that the MDS tool is capable of identifying very small non-threatening SSWC anomalies.

SSWC Burst Tests

- Will corrosion on long seam fail in brittle pipe?
- If no, then only threat associated with corrosion of or along a seam weld is selective seam weld corrosion (SSWC)
  - For corrosion that would pass B31G or RSTRNGTH, KAPA or other assessment

Improve ILI Quantification of Metal Loss Features in Dents

ASME B31.8
851.4.1 Definition of Injurious Dents and Mechanical Damage

- Dents are indentations of the pipe or distortions of the pipe's circular cross section caused by external forces.
- Plain dents are dents that vary smoothly and do not contain creases, mechanical damage, corrosion, arc burns, girth, or seam welds.

Rules on Dents with metal loss

- Events in the 1990s shaped the
  - Edison New Jersey
  - Potomac
  - Bellingham
- All mechanical damage
- All pigged, but anomaly at failure site missed
  - Post failure analysis showed an anomaly present
- All had significant public scrutiny

Subpart O – Gas Transmission Pipeline IM
192.933 What actions must be taken to address integrity issues

- For Immediate Conditions, a pressure reduction must be implemented until the condition is repaired.
- Immediate Conditions:
  - Remaining strength is less than or equal to 1.1 x MAOP
  - **A dent with any indication of metal loss, cracking, or a stress riser**
  - An anomaly judged to require immediate action

ASME B31.8 Gas Transmission and Distribution Piping Systems
841.2.4 Pipe Surface Requirements

- A dent which contains a stress concentrator such as a scratch, gouge, groove, or arc burn shall be removed by cutting out the damaged portion of the pipe as a cylinder.
- All dents that affect the curvature of the pipe at the longitudinal weld or any circumferential weld shall be removed.

ASME B31.8 Gas Transmission and Distribution Piping Systems
841.2.4 Pipe Surface Requirements

- All dents that exceed a maximum depth of 1/4 in. in pipe NPS 12 (DN 300) and smaller or 2% of the nominal pipe diameter in all pipe greater than NPS 12 (DN 300) shall not be permitted in pipelines or mains intended to operate at hoop stress levels of 40% or more of the specified minimum yield strength.
- When dents are removed, the damaged portion of the pipe shall be cut out as a cylinder. Insert patching and pounding out of the dents is prohibited

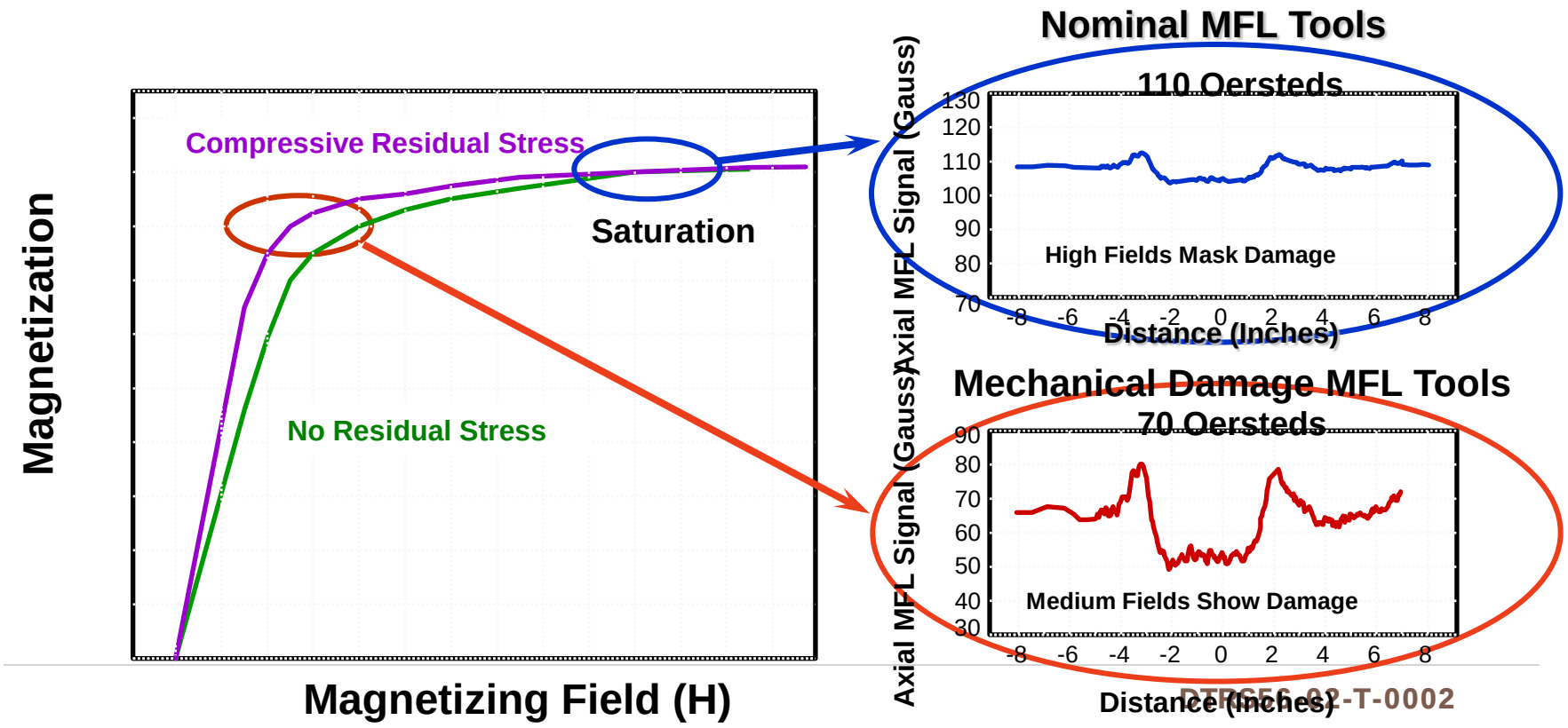
ASME B31.8
851.4.1 Definition of Injurious Dents and Mechanical Damage

- Mechanical damage is damage to the pipe surface caused by external forces. Mechanical damage includes features such as creasing of the pipe wall, gouges, scrapes, smeared metal, and metal loss not due to corrosion.
  - Cracking may or may not be present in conjunction with mechanical damage.
  - Denting of the pipe may or may not be apparent in conjunction with mechanical damage.
- Plain dents are defined as injurious if they exceed a depth of 6% of the nominal pipe diameter. Plain dents of any depth are acceptable provided strain levels associated with the deformation do not exceed 6% strain.

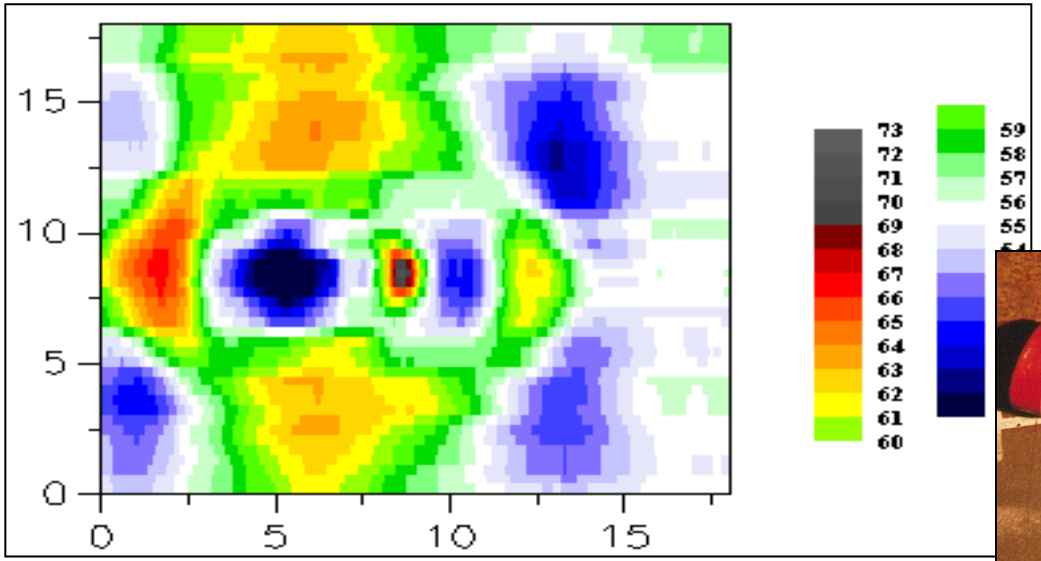
Fundamental Research on Low Field MFL

- In response to the Edison New Jersey failure
- Two other accidents after
  - Potomac
  - Bellingham
- Funded by
  - DOT – OPS
  - GRI with DOT cofunding
  - PRCI after FERC funding of GRI stopped

Magnetization Level & Mechanical Damage

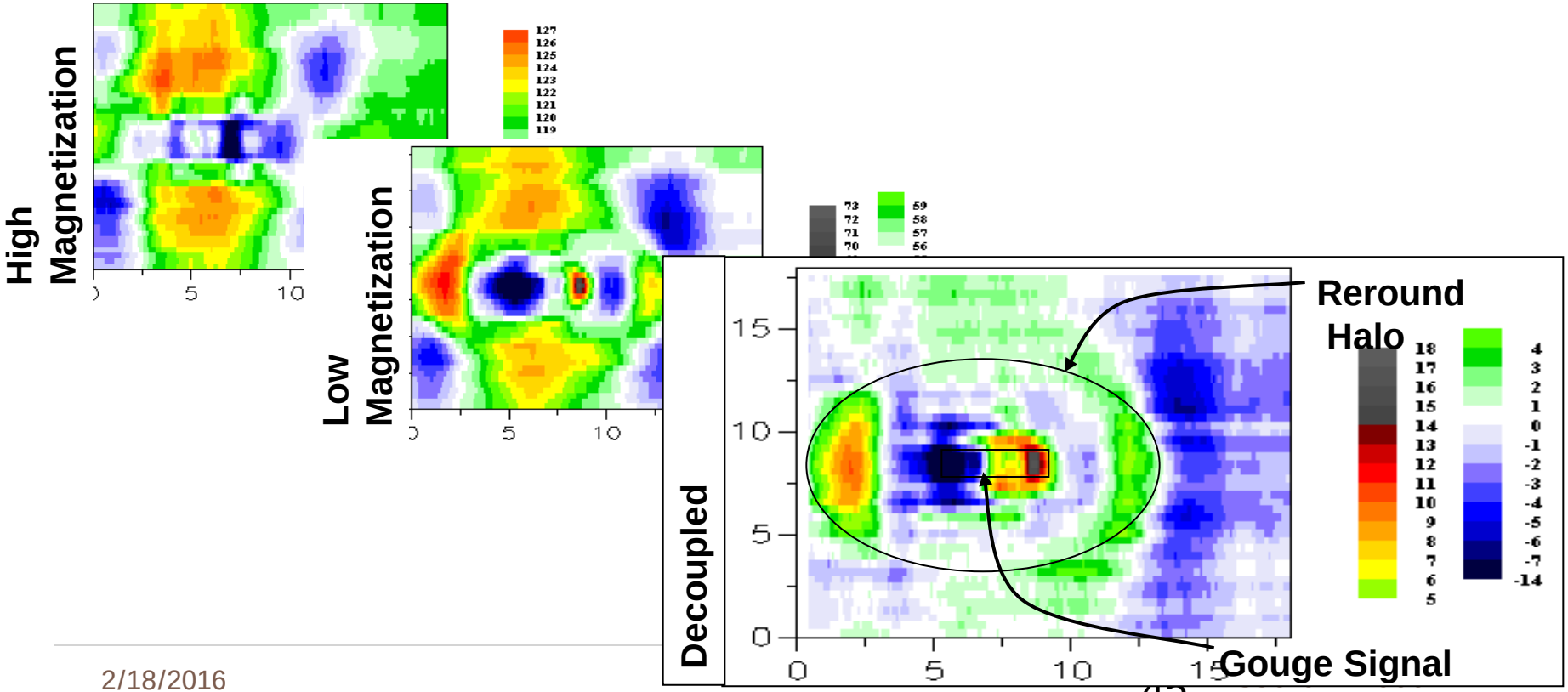


Low Magnetization Signal



At low magnetization levels the signals are complex

Decoupling Example



Final Priority Ranking

Rerounding Index (0,1, or 2)
Plow Index (0,1 or 2),
Wall Stress Index (0,1 or 2),
Remanent Field Index (0,1 or 2)

"Initial" Ranking

Initial Ranking Adjusted Based on Analysis of Decoupled MFL Patterns

Final Ranking

- High
- Moderate-High
- Moderate
- Moderate-Low
- Low

Index Sum Value Moves Ranking Up 1-Unit

Implementation

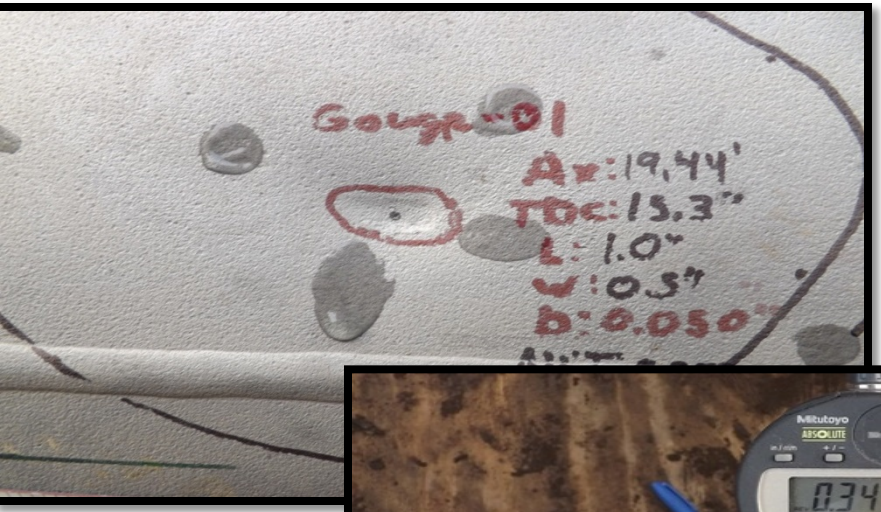
- Implemented by
  - Tuboscope with PRCI funding
  - Rosen with DOT/PRCI funding
  - TD Williamson
- Parallel PRCI work to define severity
  - started in 2005 and still an active project
- The lack of a adequate failure model has limited the use of this approach

Algorithm development

- Conservatively classify mechanical damage
  - Any gouging in dents is severe
- Dismiss many corrosion anomalies in dents as not severe

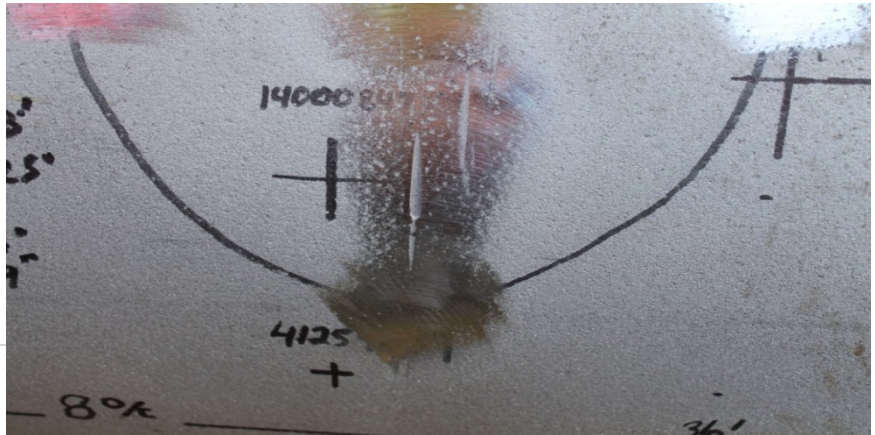
- In the ditch methods must be able to detect gouging

ITDM Dent Evaluation: Curvature And Depth



ITDM Dent Evaluation: Local hardness

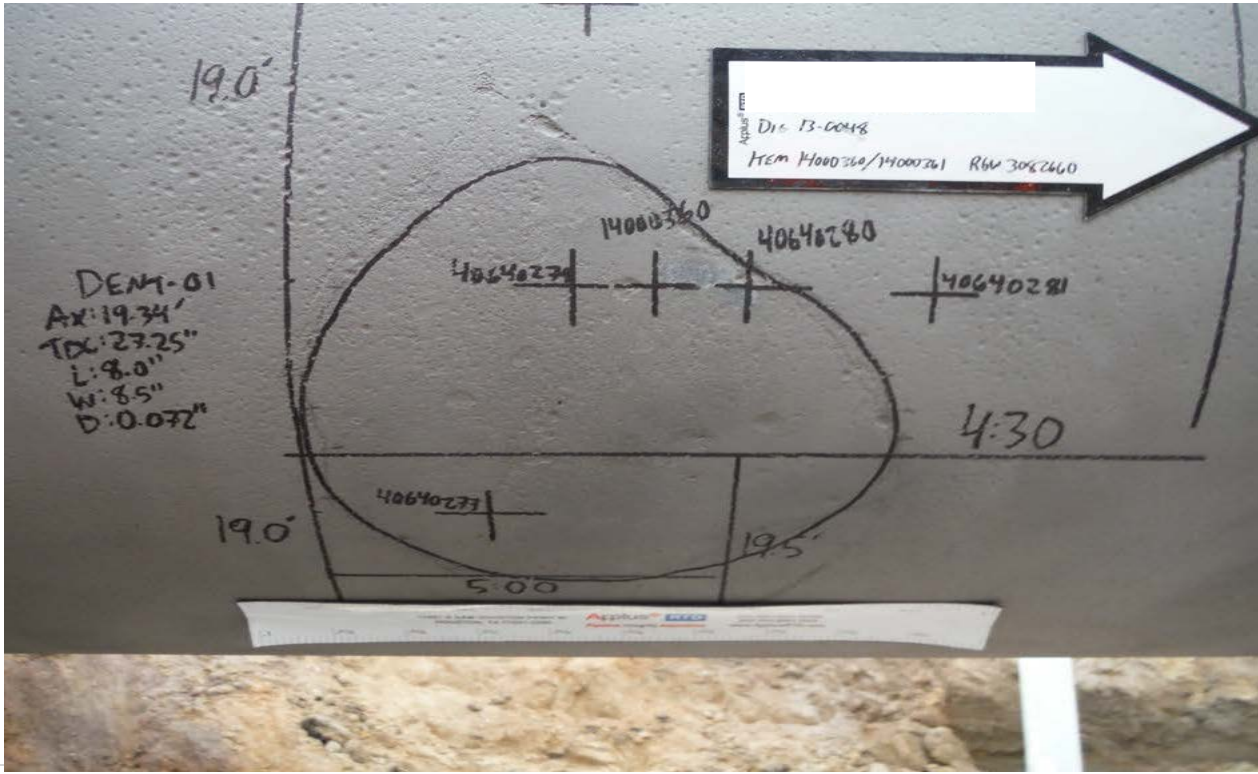
- Hardness testing according to the UCI method
  - Ultrasonic Contact Impedance standardized according to ASTM A 1038 and DIN 50159
  - MIC 10
- The diamond slightly indents in the material's surface
- The hardness is electronically measured
- Etching for local grain structure changes



Dent Example 3

Inspection Revealed

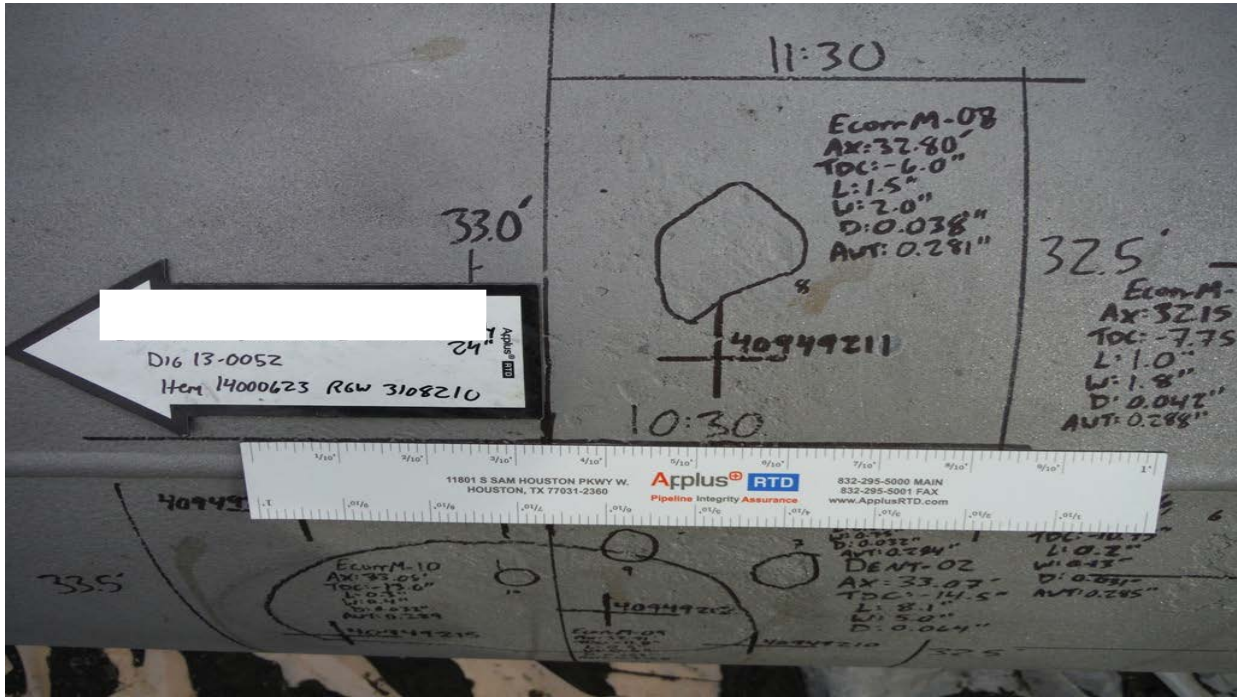
- 2 Dents with a depth of 0.107”– (0.45% OD)
- 11 External metal loss locations. Maximum depth of 0.047”– (16.7% NWT)



Dent Example 4

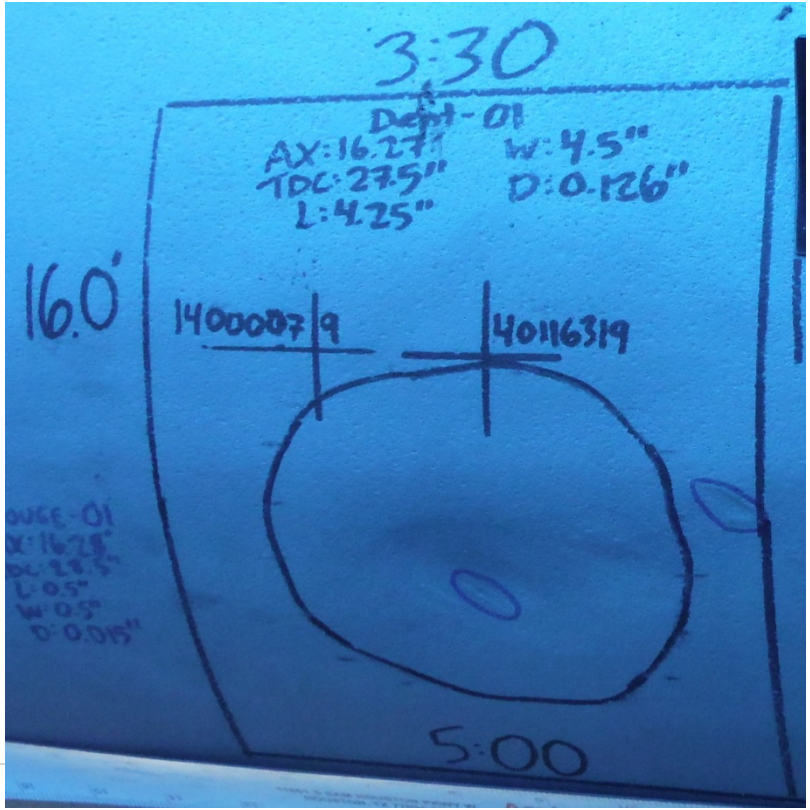
Inspection Revealed

- 2 Dents with a depth of 0.064in (0.26% OD)
- 10 External metal loss locations. Maximum depth of 0.053 in.(18.9% NWT)



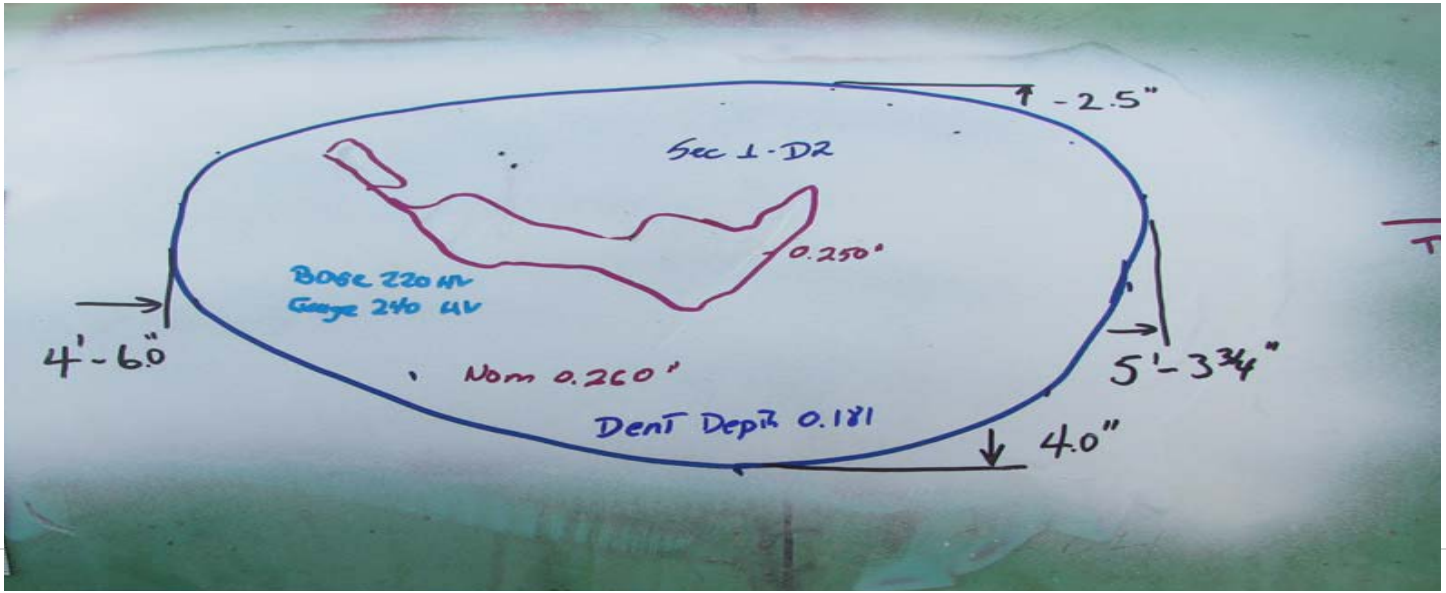
Dents from ILI Runs

- Called as dents with metal loss in ILI logs
- Classified in the field as either gouge, corrosion, or none
- Photo shows gouging



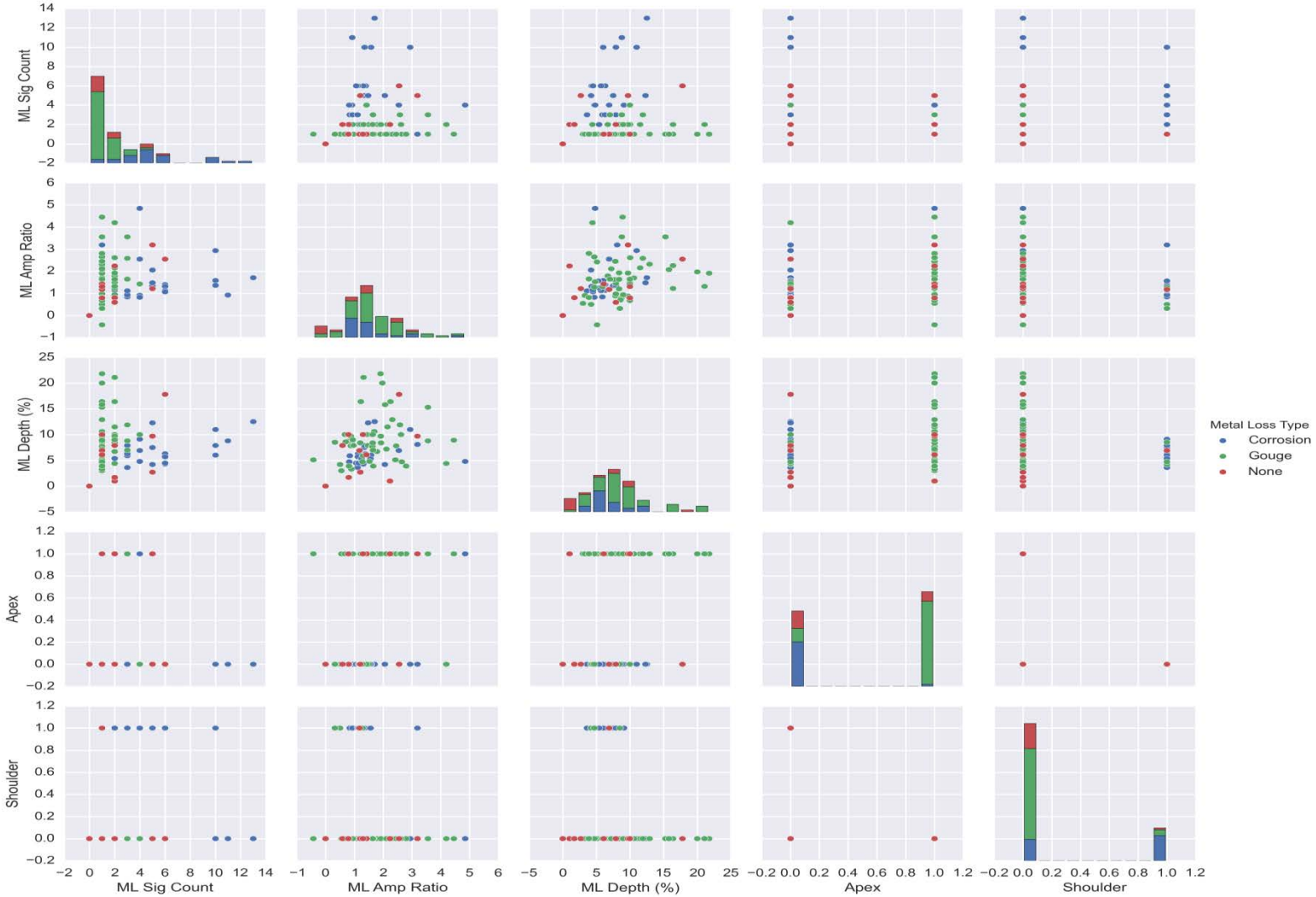
Manufactured Dents

- Produced by striking pressurized pipe with backhoe bucket
- Shallow gouging in large majority, but some plain dents



Mechanical Damage Classifier

- Distinguish *dent with corrosion* from *dent with gouge*
- Train a model to recognize these types based upon ILI signal features
  - MFL to LFM amplitude ratio
  - Number of metal loss signatures
  - Location of metal loss signatures (apex, shoulder, both)
  - Estimated metal loss depth
- 88 dent samples available from combination of actual ILI runs and pull tests through manufactured dents


ML Sig Count
ML Amp Ratio
ML Depth (%)
Apex
Shoulder
Metal Loss Type
Corrosion
Gouge
None

Mechanical Damage Classifier Performance

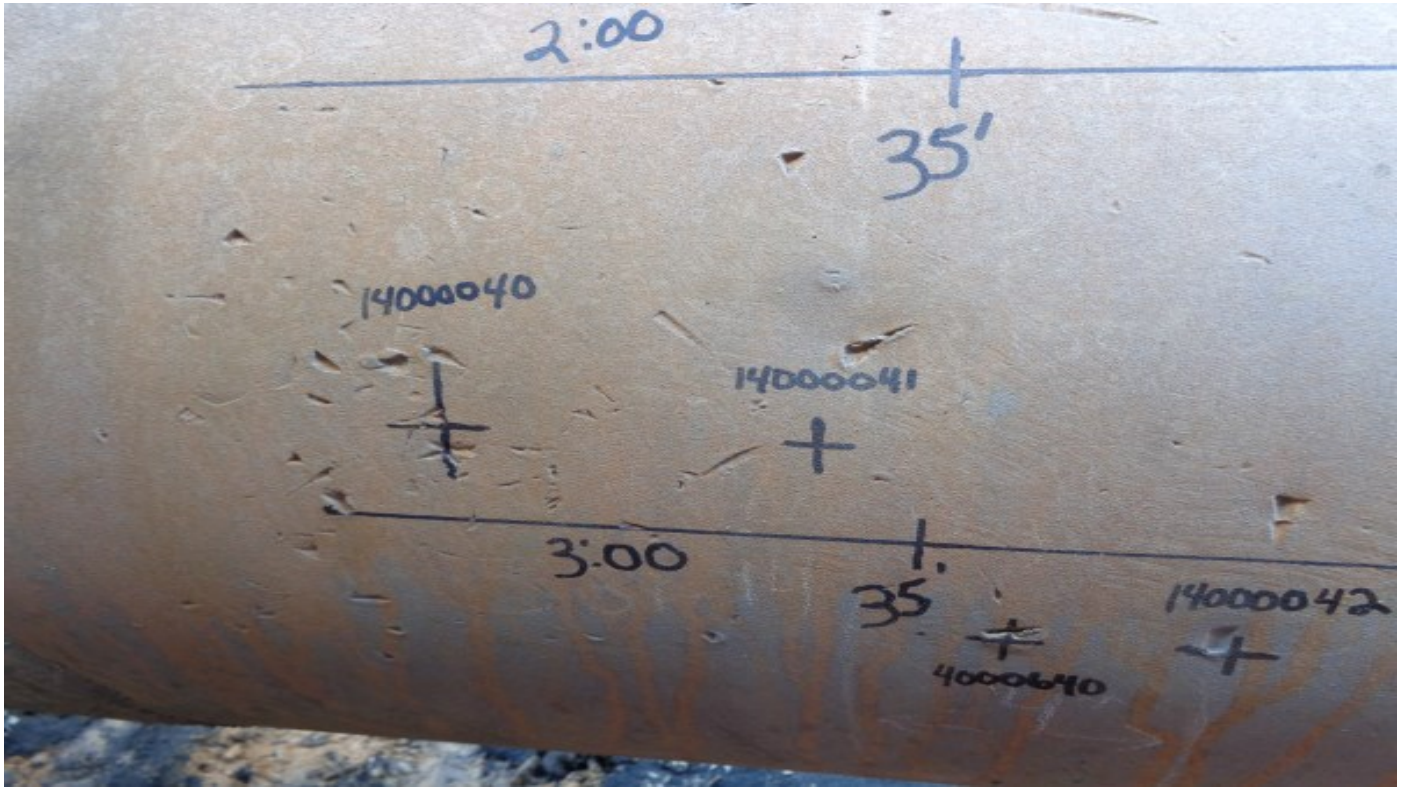
	Called Corrosion	Called Gouge	Called None
Is Corrosion	18	6	0
Is Gouge	1	48	1
Is None	2	8	4

Table 2. Classifier confusion matrix.

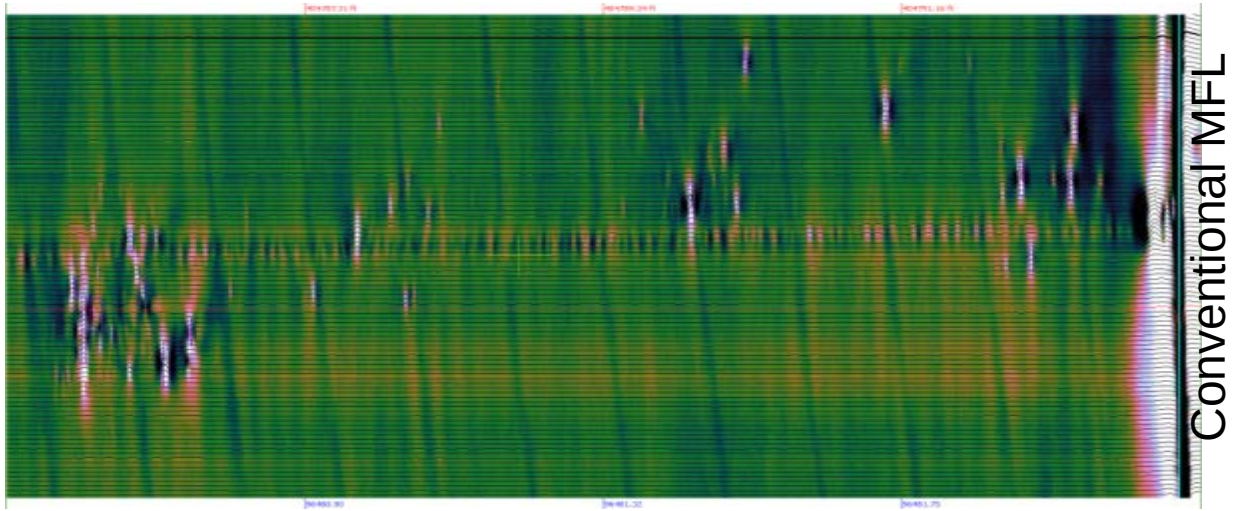
	Precision	Recall	Samples
Corrosion	0.86	0.75	24
Gouge	0.77	0.96	50
None	0.80	0.29	14
average / total	0.80	0.80	88

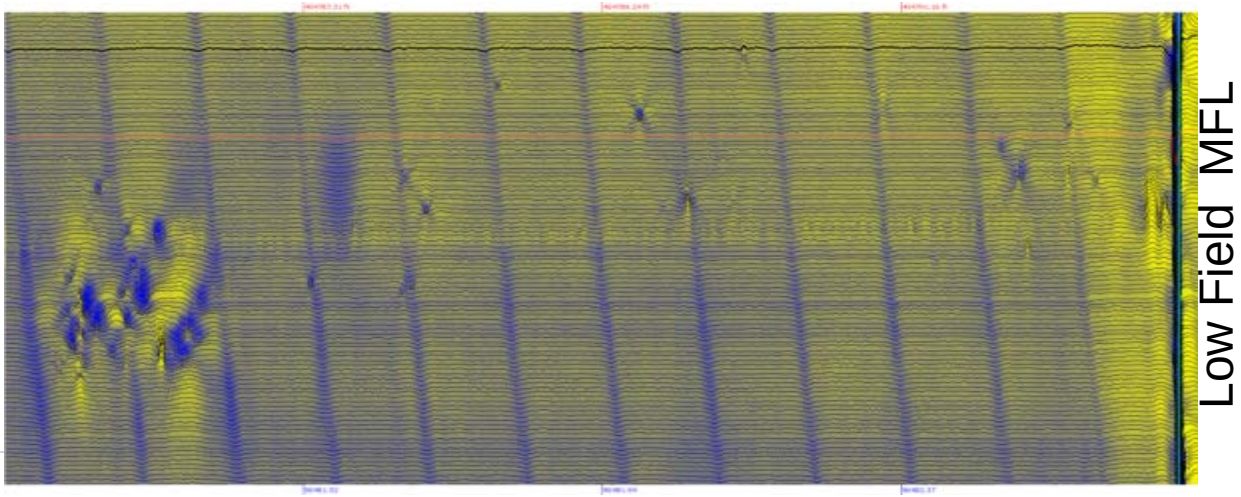
Table 3. Classifier performance summary.

The Gouging that was call corrosion



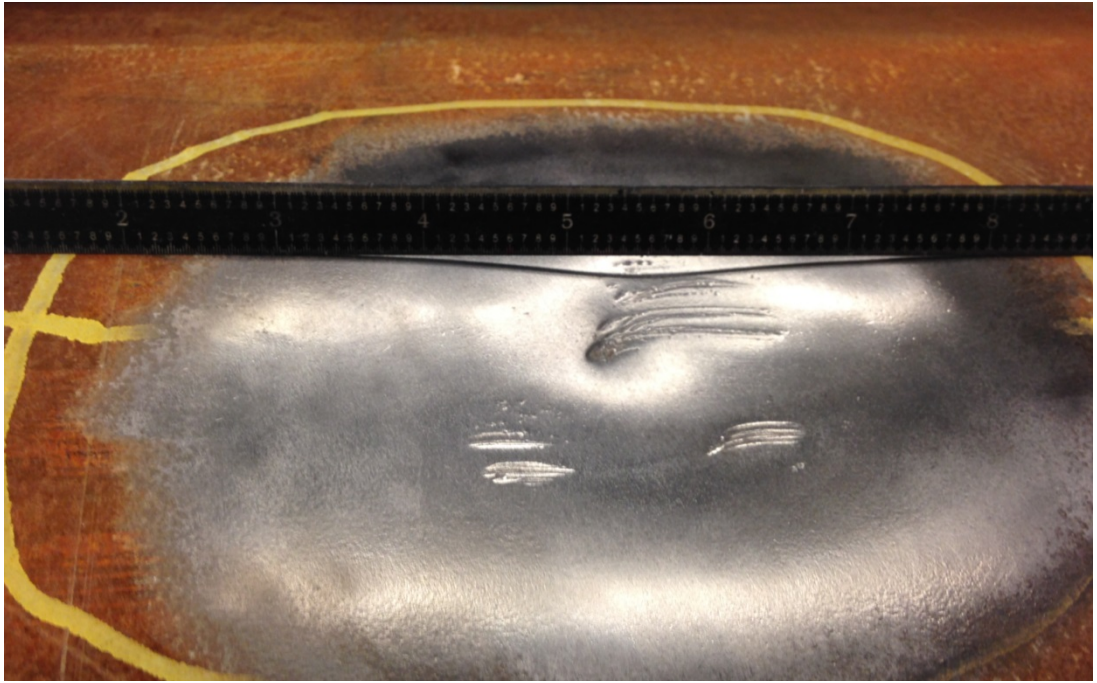
- Algorithm fooled by excessive number of hits
- Clear LF Signals would classify as Mechanical Damage if reviewed manually





Pressure tests

- Detected gouging
- Subjected to internal pressure
  - 100% SMYS
  - Repeated 5 times



Summary on Dents with Metal Loss

- A process was developed that conservatively detects gouging in dents
  - Any gouging in dents is severe
  - Detects small gouges which probably are not severe
- To be conservative, some corrosion anomalies in dents that are not severe will be flagged

Improve ILI Quantification of Wide-Area Corrosion

Wide Area Corrosion

Field measurements

ILI Call:

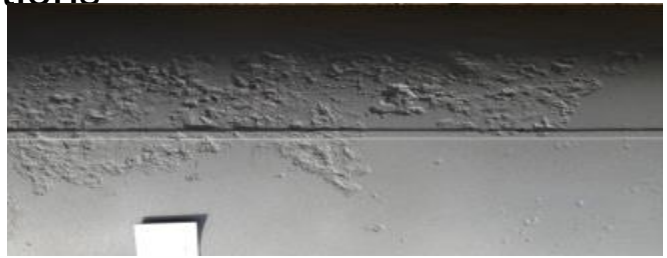
- 13 metal loss features, clustered in four locations

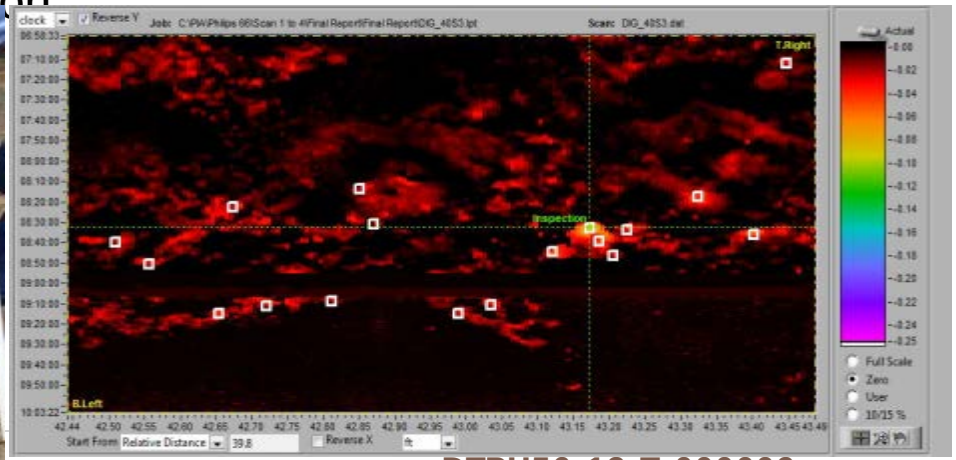
Observation

- corrosion.

Action

- Laser scanning with pit gage verification

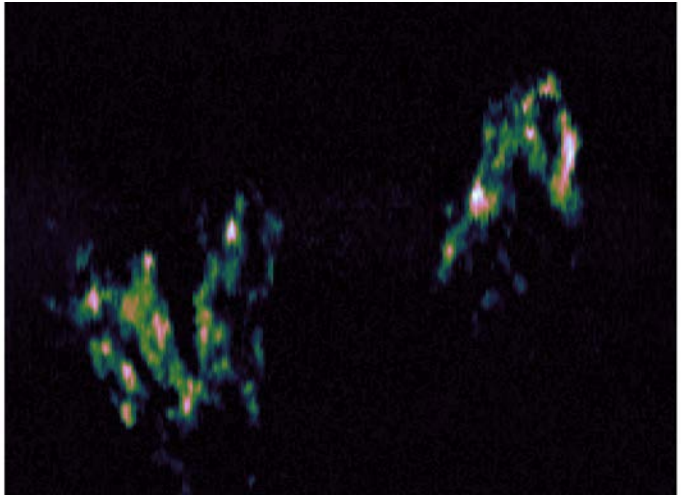




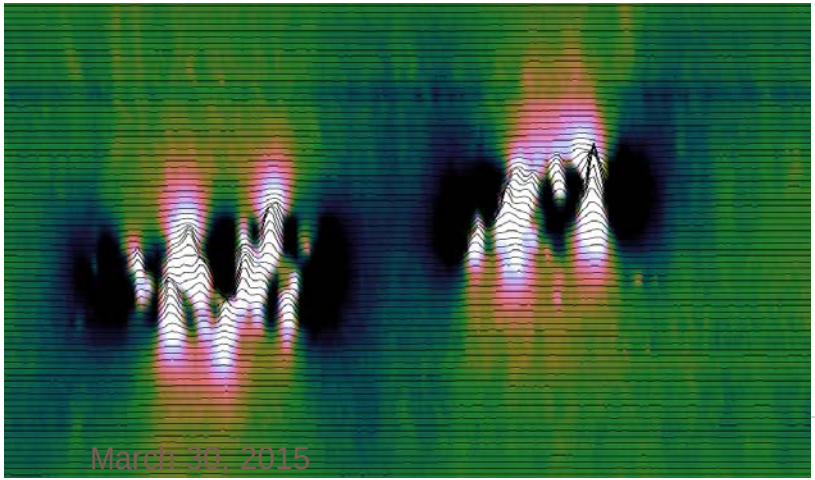
Breaking Up Complex Corrosion

- Complex corrosion patterns create ILI signatures that can be difficult to interpret
- First: Improve identification accuracy by using high resolution laser scan *truth* to train an improved model for dividing up the complex corrosion into ILI call boxes
- Second: Improve sizing models for complex corrosion

Laser
(Truth)



MFL



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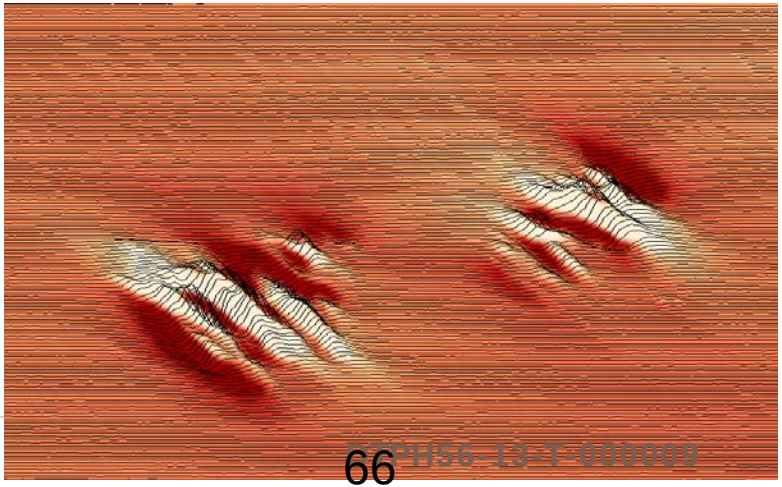

Metal loss sizing status

- The complex and interacting metal loss model development is a longer process.
- The SSWC and dent with metal loss classifiers mainly examined detection of these anomalies.
  - Detection algorithms primarily require data from smaller anomalies to demonstrate the effectiveness for detection.
- Metal loss sizing algorithm development requires data from all sizes of corrosion, from small inconsequential to large repairable anomalies.
- The available data was sufficient to develop a frame work for a new sizing model for metal loss. Additional inspection and excavation confirmation data are required to complete the algorithms.

Summary

Summary

For the three challenges for interaction metal loss defects

1. Denting and metal loss: Classifier developed that conservatively classifies metal loss caused by gouging from many general pitting
2. Corrosion on the seam: Classifier developed that conservatively differentiates between crack-like selective seam weld corrosion (SSWC) from conventional corrosion that just happens to encounter a low frequency ERW seam
3. Wide area corrosion (pits in patches): Some of the pits within a large corrosion area may not be detected or sized, and failing to include these defects may underestimate the amount of missing metal when attempting to calculate a failure pressure. Framework developed but more training data needed to fully develop the algorithm.

Safety first,
Safety always

Did we determine all risk controls needed to have no harm to people?

Risk Assessment

Personal Protective Equipment

Hierarchy of Control

Outstanding Safety Issues?

Be interested

Kiefner Applus RTD