

Colonial Pipeline Company

Practical Experience on Addressing the Assessment & Management of Dents

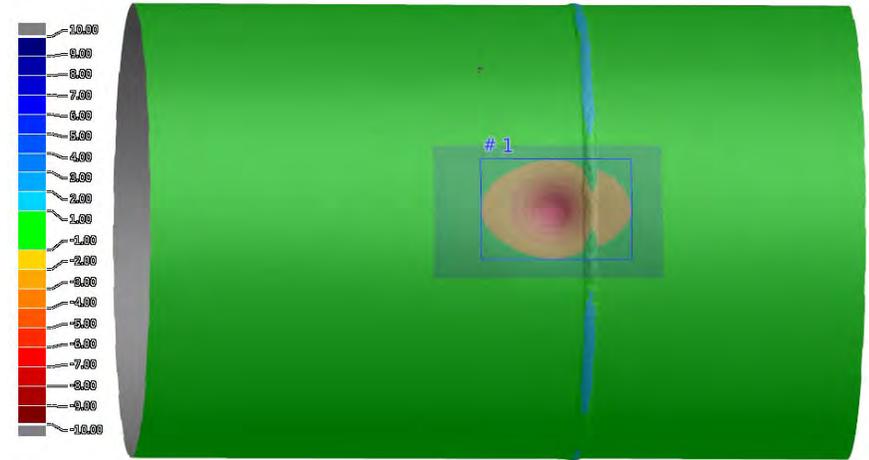
**USDOT PHMSA 2018 R&D Forum
Baltimore, MD
September 11, 2018**

**Mark Piazza
Manager, Pipeline Compliance and R&D**



Research Objective

- Improve our understanding of dent fatigue to develop appropriate inspection, response/repair, and P&M technologies, strategies and programs
- Adjust operations to reduce cyclic fatigue on system
- Apply R&D results to evaluate and prioritize dents and deformations that represent a potential for failure



Hazardous Liquids Final Rule

- Liquids industry petitioned to allow for an industry recognized engineering analysis to determine those dents that are non-injurious and require no further investigation

- Engineering analysis accepted for cracks, not dents

notify the appropriate PHMSA Region Director when unable to inspect infrastructure impacted

by extreme weather within 72 hours; 2) PHMSA is allowing a specified engineering critical

assessment (ECA) to extend the repair deadline with regard to SCC and SSWC but not for dents:

- With Final Rule pending, what are options?
- What tools are available for managing shallow dents?



NTSB Recommendation

- P-17-1: *Work with pipeline trade and standards organizations to modify the pipeline dent acceptance criteria to account for all the factors that lead to pipe failures caused by dents, and promulgate regulations to require the new criteria be incorporated into integrity management programs*
- Regulations are not vague
- Support for revised/alternate response criteria
- Addressing the shallow dents that require response
- Resource allocation to true threats – improving pipeline safety

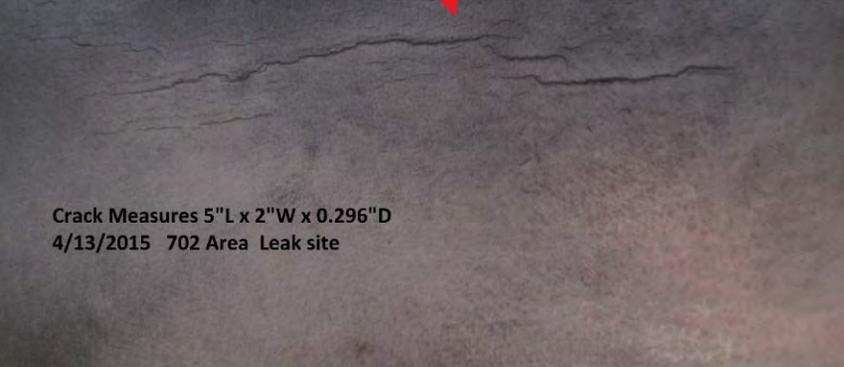
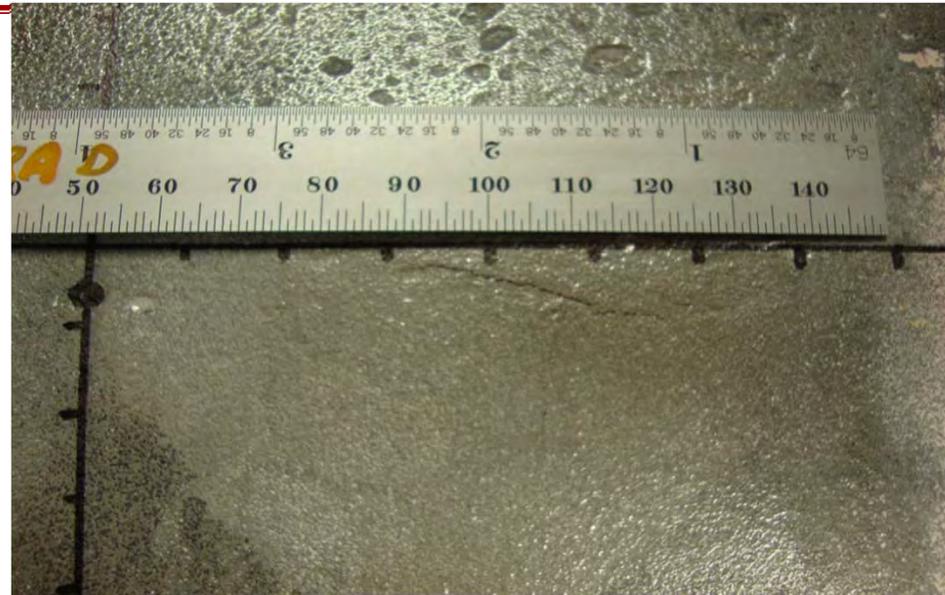
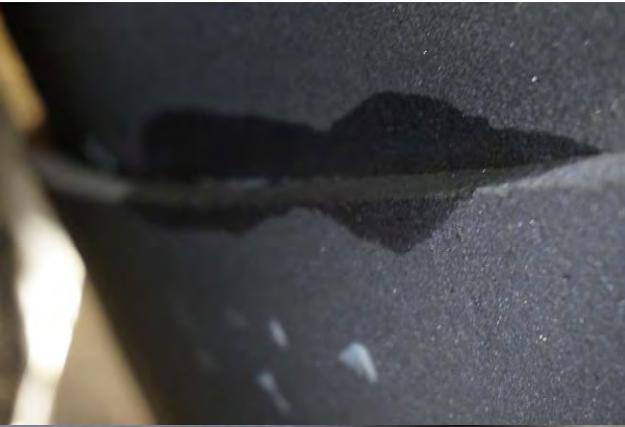


Pipeline Inspection & Repairs

7 of 8

Comments: SCC colony.





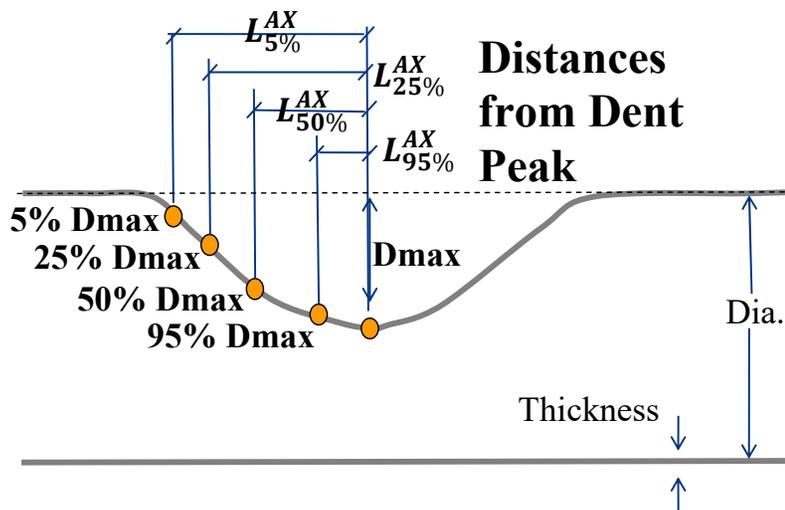
Crack Measures 5"L x 2"W x 0.296"D
4/13/2015 702 Area Leak site



Key Outcomes of Dent Fatigue Research

- Dent shape parameter (not depth!)
 - Incorporated into pipeline operator ILI specifications
 - Sets a standard for dent/deformation ILI reporting requirements
 - Used in Level 1, 2, 3 analysis

PRCI Dent Shape Parameter Specification

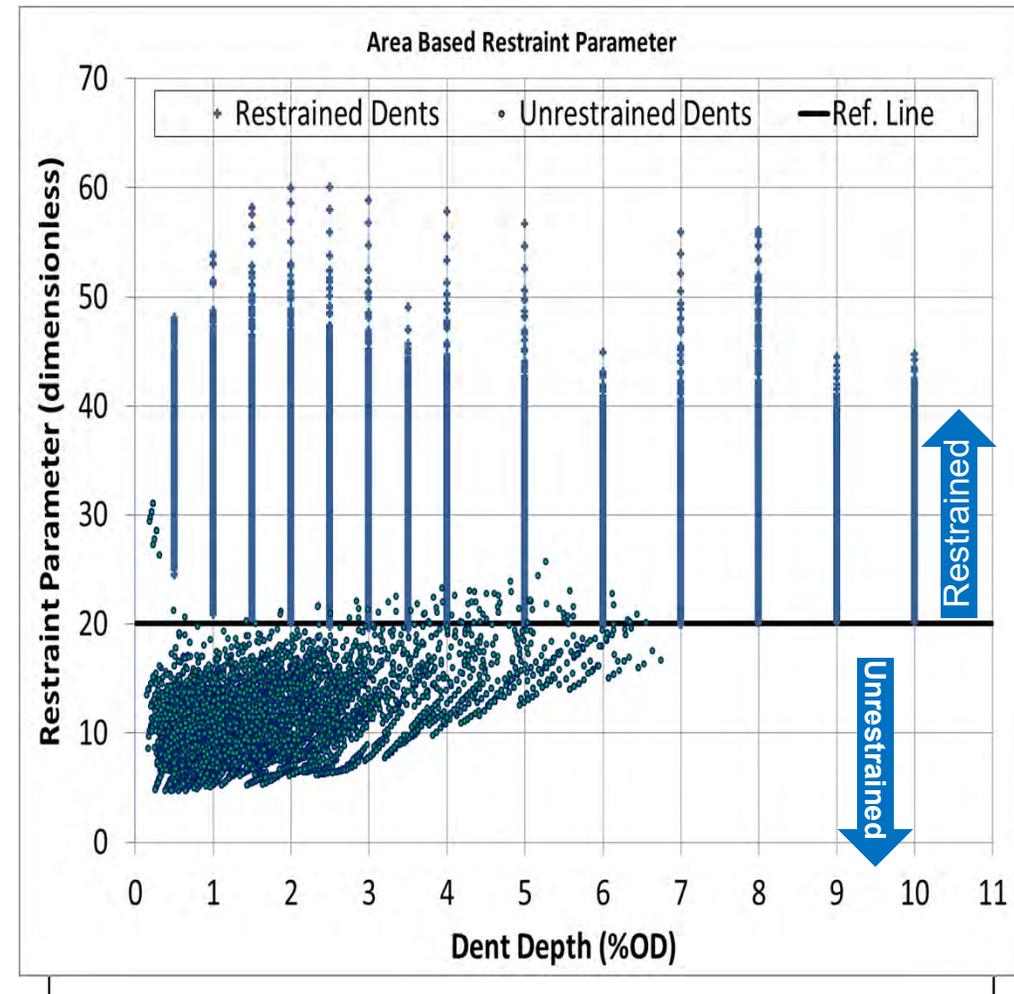


- PRCI MD 4-9 Technical Note
- Develop shape parameter using characteristic lengths measured across the dent profile
- Use calculated shape parameters, pipe grade, and SCADA data to rank shape severity (L1) and /or fatigue severity (L2)
- L3 – full FEA; complex shapes

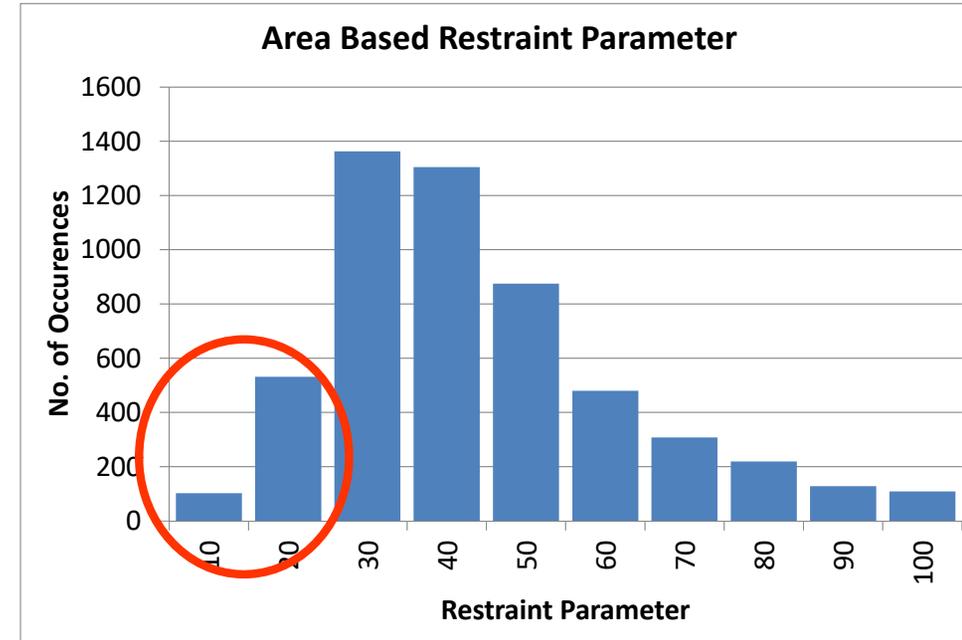
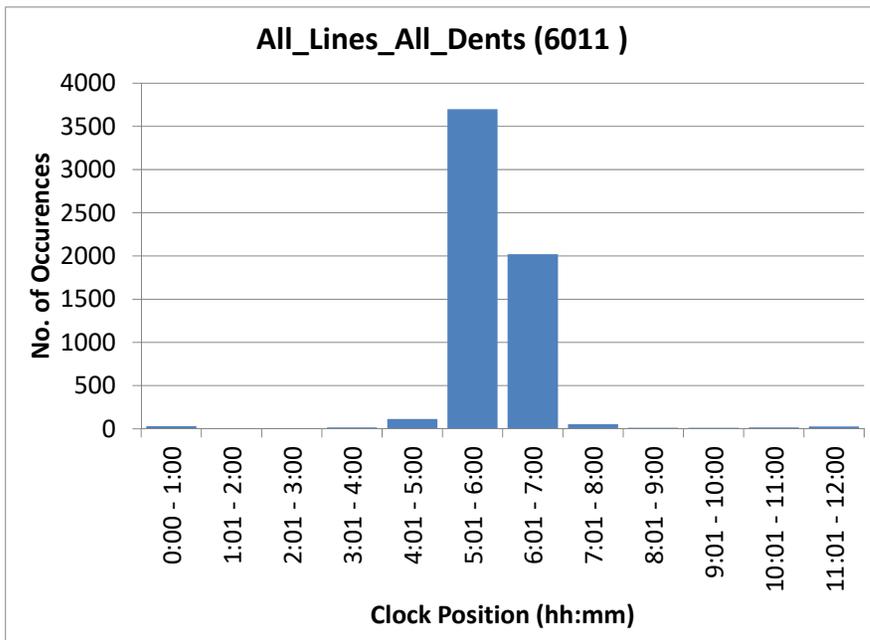
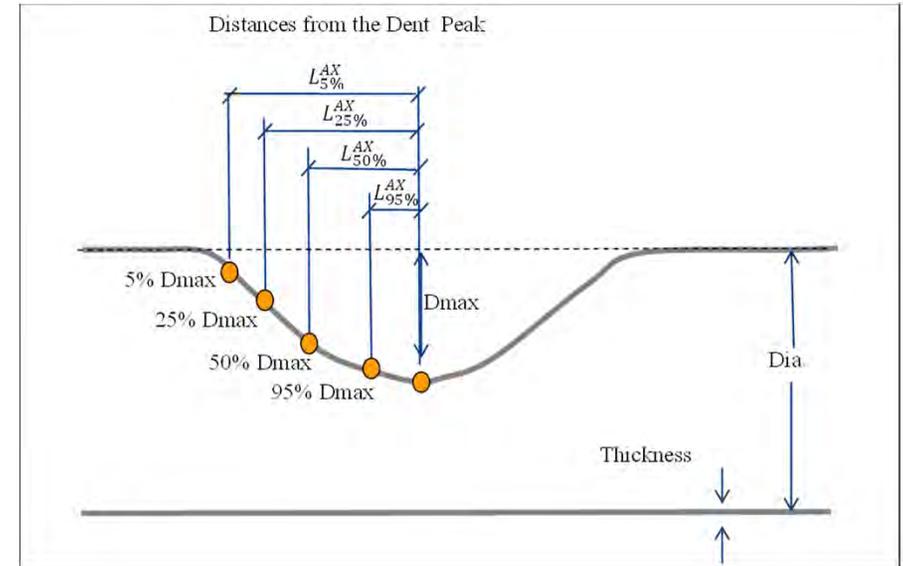
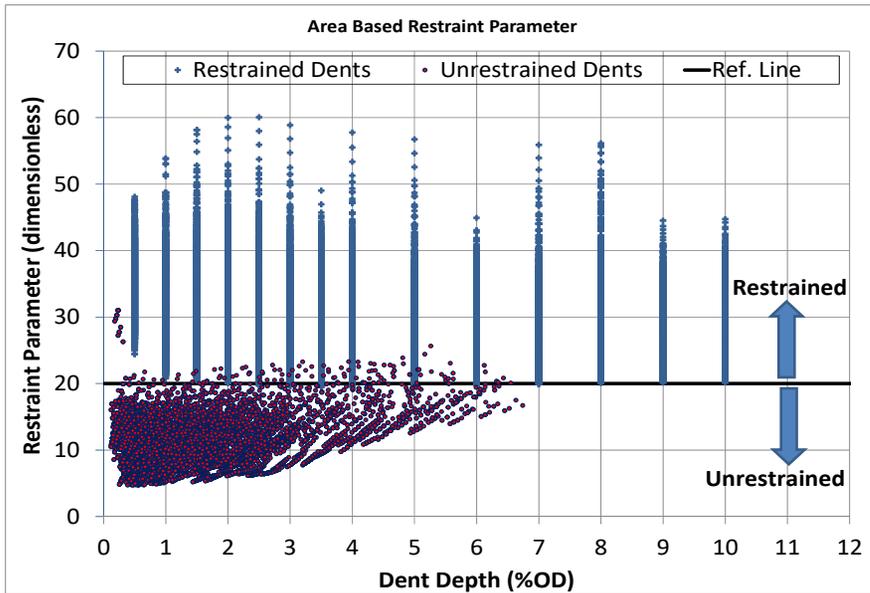


Key Outcomes of Dent Fatigue Research

- **Dent restraint parameter – restrained vs. unrestrained affects fatigue life**
 - **Restrained – longer life**
 - **Unrestrained – reduced life**
 - **Bottom-side dents have higher restraint potential**
 - **Previously excavated dents: restrained and unrestrained**



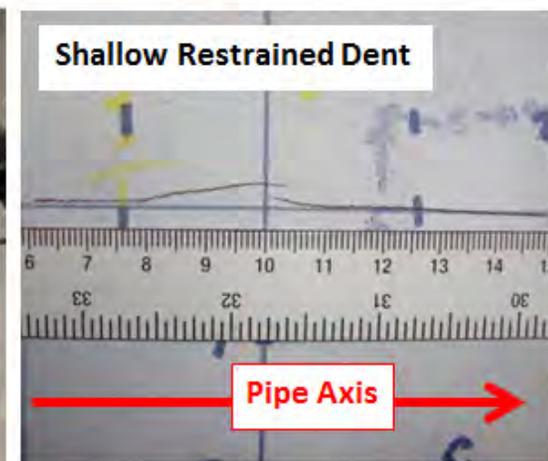
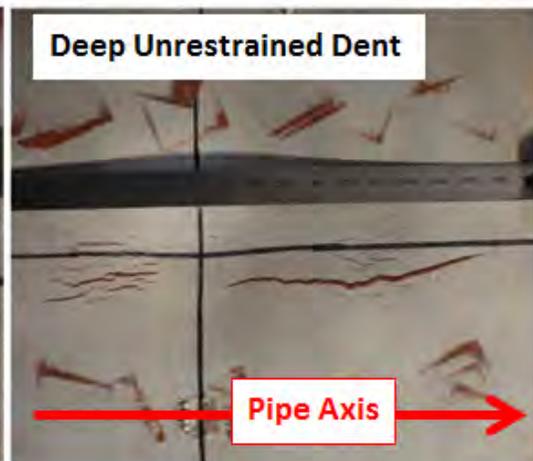
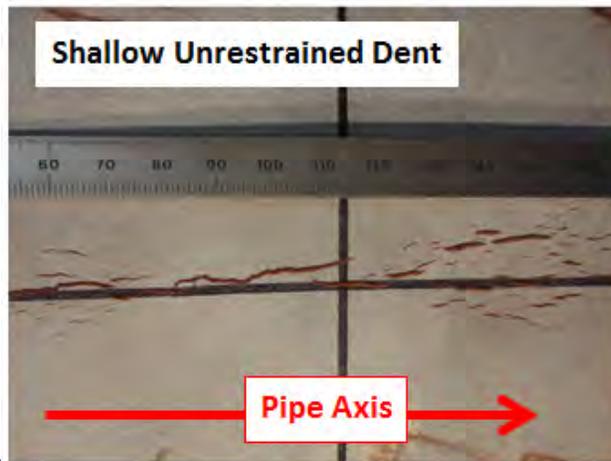
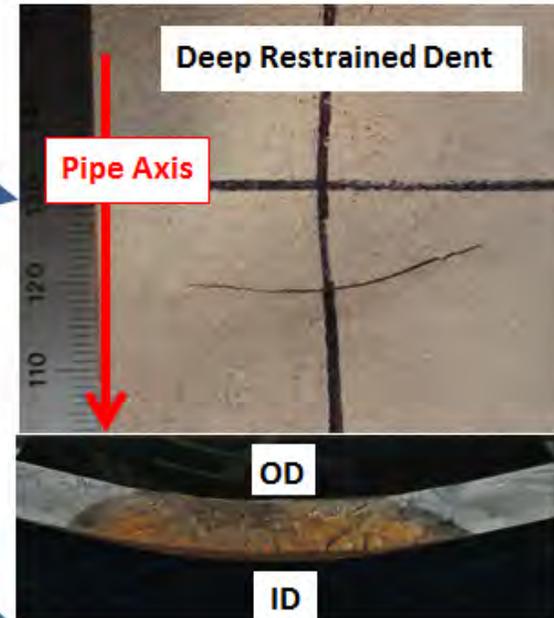
Analysis of Restraint Condition



Key Outcomes of Dent Fatigue Research

Dent Fatigue Crack Location, Orientation and Surface

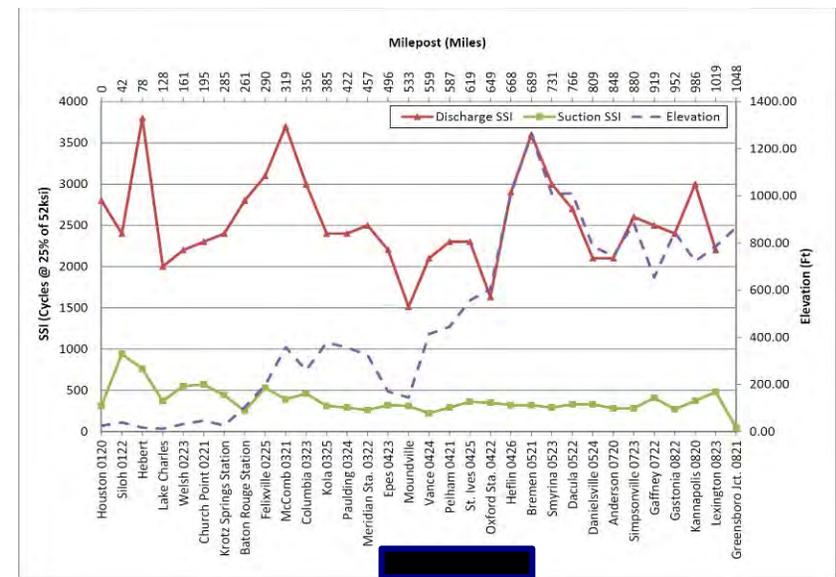
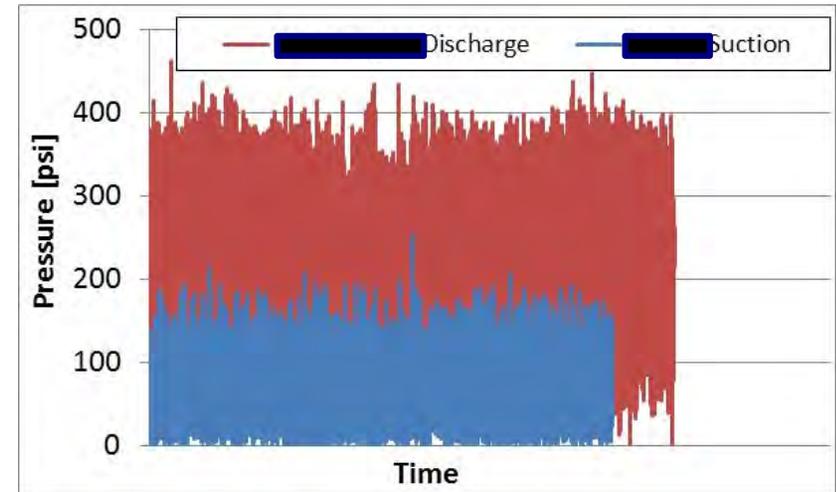
Dent Type	Depth	Shape	Crack Location	Orientation
Restrained	Deep (> 5%)	Blunt or Sharp	Axial Shoulder (one or both) ID Initiation	Circumf.
Restrained	Shallow ($\leq 2\%$)	Blunt or Sharp	Center of dent ID Initiation	Axial
UnRestrained	Deep (> 1.5%)	Blunt or Sharp	Axial Shoulder OD Initiation	Axial (Multiple)
UnRestrained	Shallow ($\leq 1.5\%$)	Blunt	Center of dent OD Initiation	Axial (Multiple)
		Sharp	Axial Shoulder OD Initiation	Axial (Multiple)



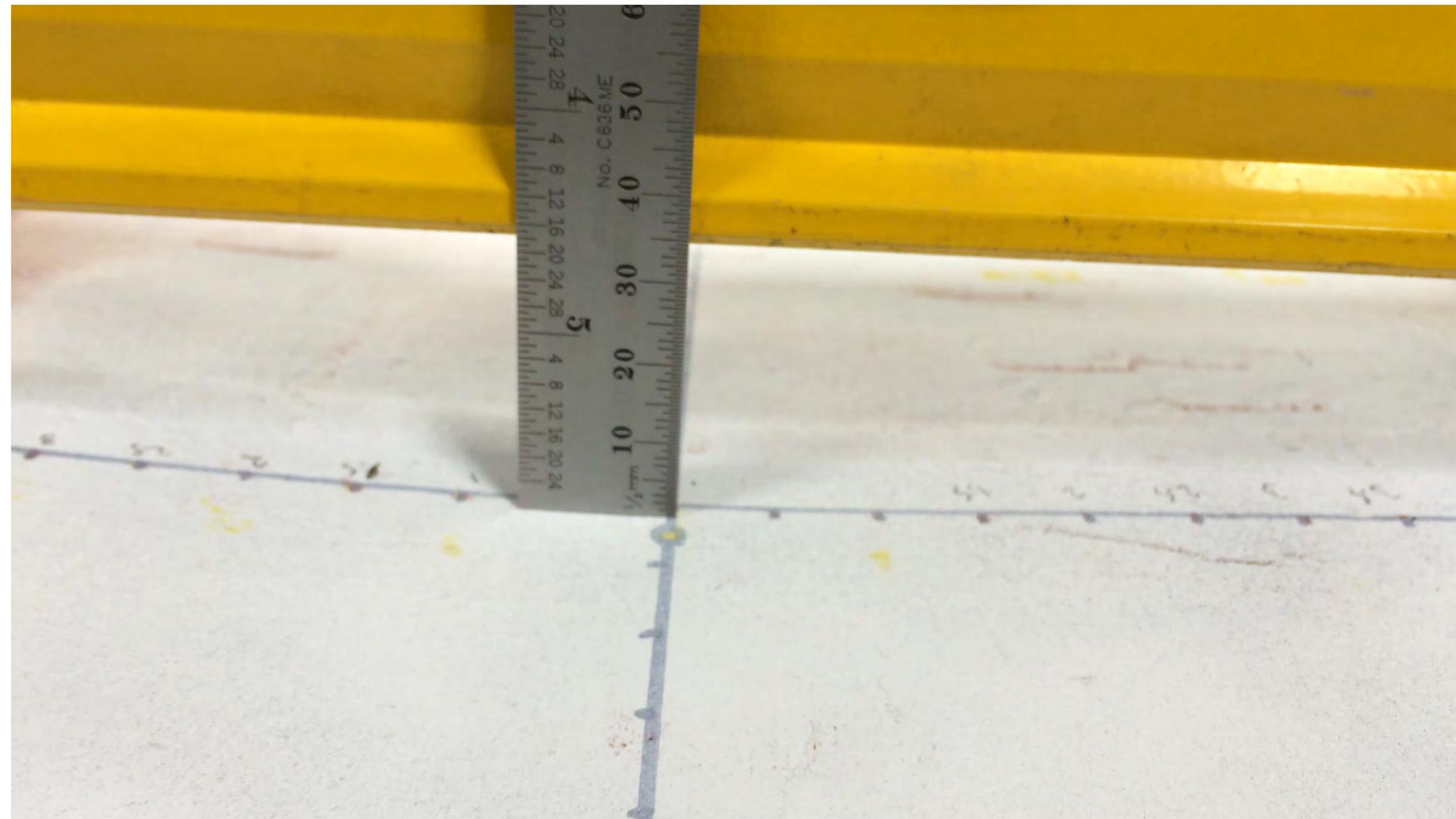
Key Outcomes of Dent Fatigue Research

Pressure Cycle Management

- # of cycles and magnitude of cycling loading influence dent fatigue failure
- Pressure attenuation – discharge vs. suction
- Liquids operations vs natural gas
- Pressure cycling references in regulations
 - *Absent in PHMSA Proposed Final Rule (49CFR § 195)*
 - *Included in PHMSA Advisory for natural gas lines (ADB 2016-0131)*



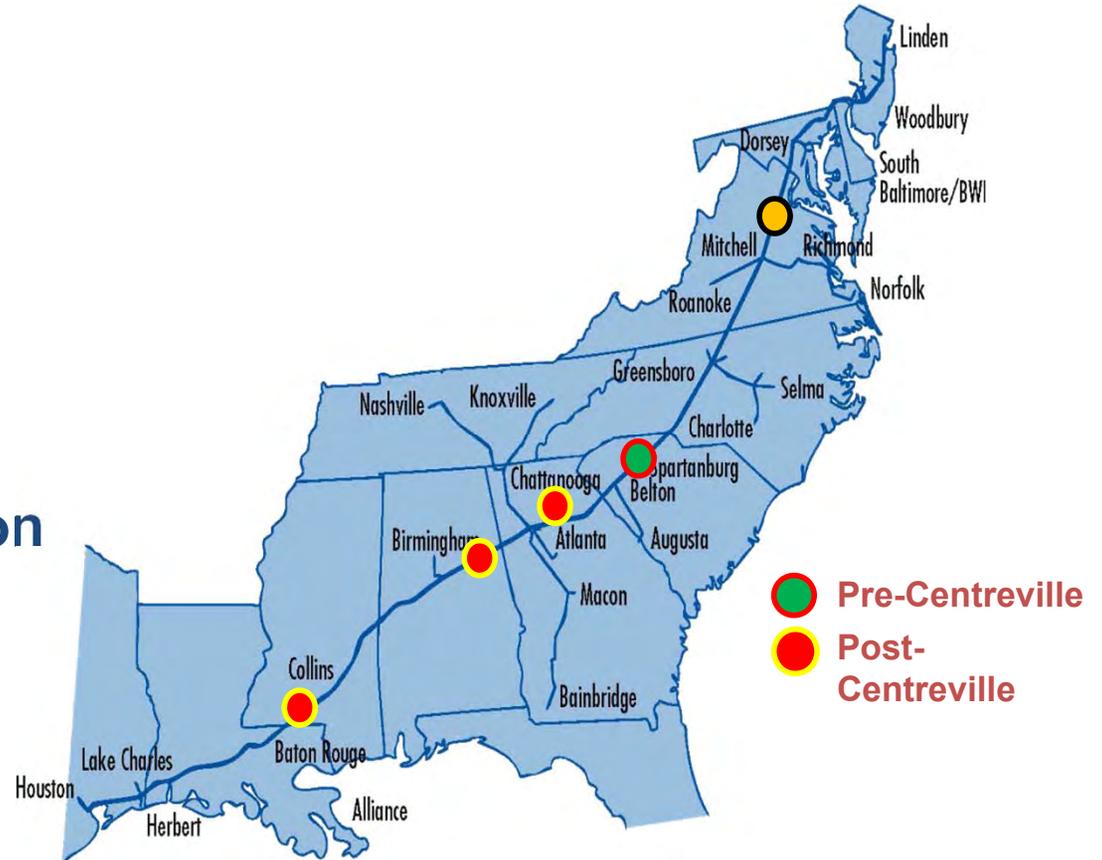
Full-scale Testing of Dent Sample



Effects of Dent Shape

■ Leak Differences

- Manufacturer
- Date of Install
- Pipe Diameter
- Coating Type
- Product Type
- Distance to Pump Station
- Terrain
- Soil Type
- Moisture Content
- Indenter Cause

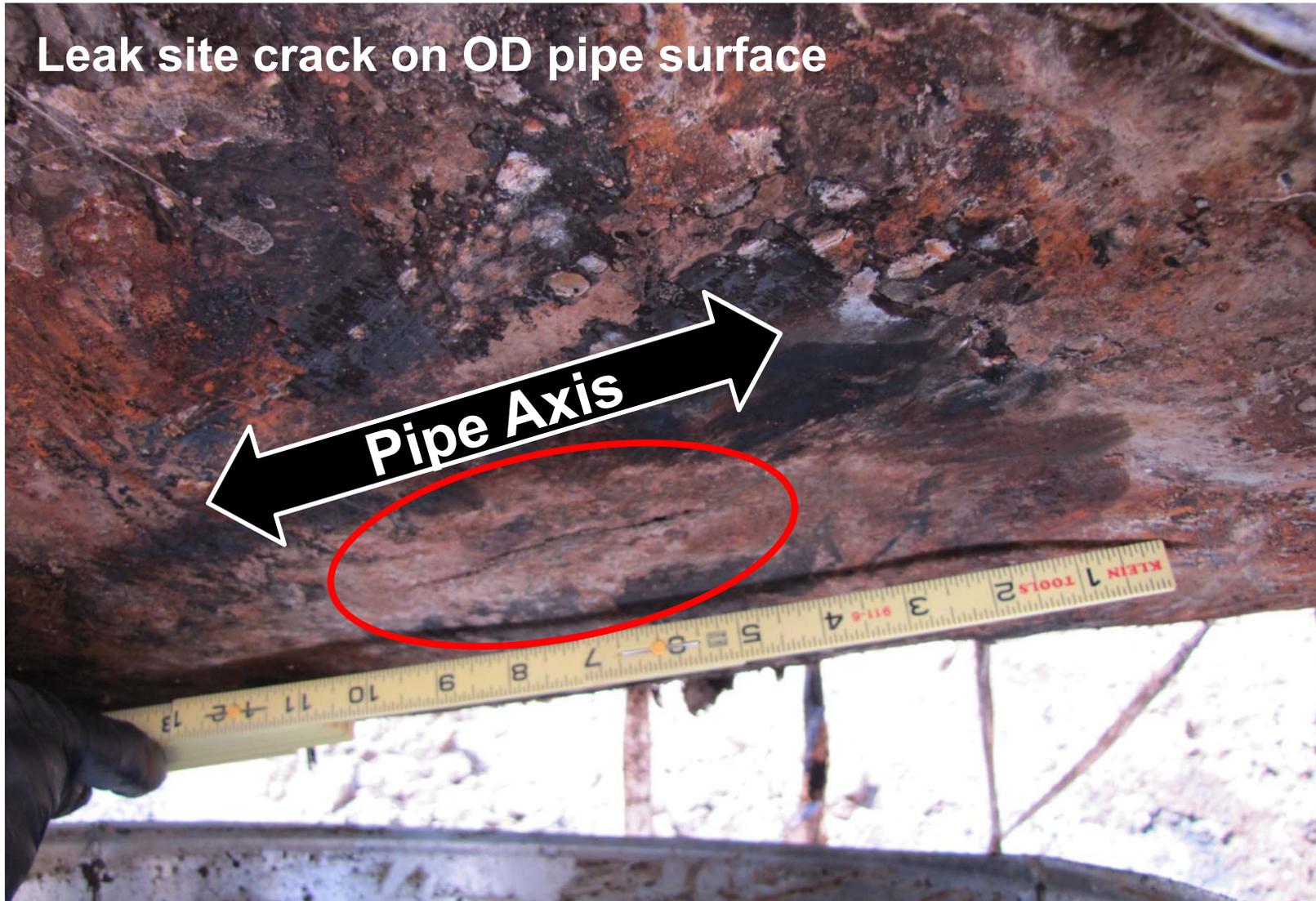


■ Leak Similarities

- Shallow Bottom Side Dents
- High D/t Pipe



NTSB Accident Investigation – Centreville, VA



Fatigue Testing of Uncracked Dent Sample

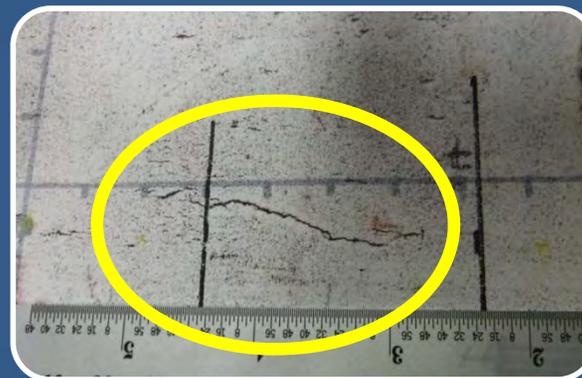
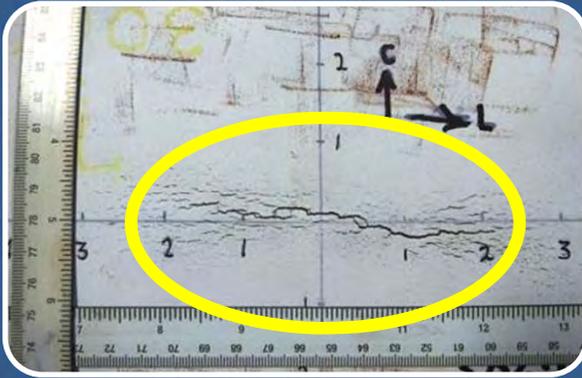


Effects of Dent Shape

3rd Dent (Fatigue Test)

Un-cracked Dent
(Fatigue Test)

Leak Site
(failed in-service)



- Fabricated dent
- 24" indenter, 1.1% deep
- Smooth dent profile
- 90 psi to 540 psi
- Unrestrained dent
- Center of dent axis
- **455k cycles to failure**

- In-service, bottom-side dent: 1.6% deep
- Smooth dent profile
- 90 psi to 365psi*
- Previously dug and remediated (2002)
- Restrained & unrestrained
- Near dent peak

- **108k cycles to failure**

- In-service, bottom-side dent: 1.6% deep
- Complex shape
- 365 psi max
- Previously dug and remediated (1994)
- Restrained & unrestrained
- Near dent peak

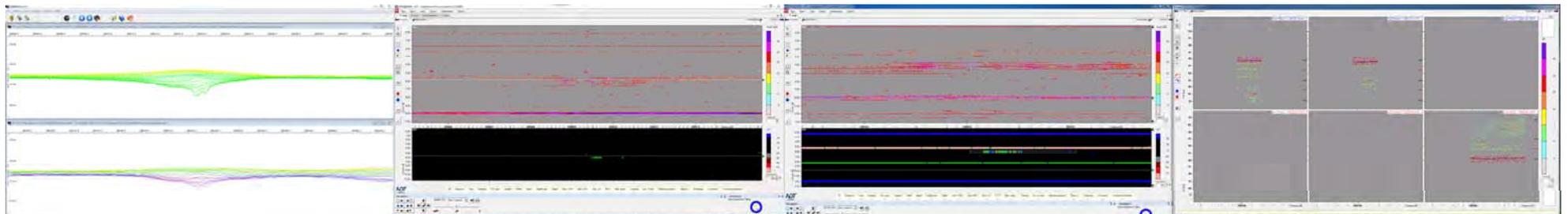
- **12k cycles to failure**



Integrating Multiple ILI Tool Runs

- Typical mainline data set
 - 3+ MFL\DEF\INS
 - 1 UT crack tool run
- All data is integrated and odometers generated for all historic tool runs
 - Previous tool runs are reviewed in conjunction with most current tool run
 - Prior dig data is integrated - allows for tool validation prior to digging
 - All dents are manually reviewed in raw data (recall DRRPM)

1	ANOMALYID	AF	ENDORC	ODO2015	CRACK201	COMBO201	ORCPC	Altstation	USWELD	DSWEL	RIENTA	JOINTLENG	VENDORNOTES	PTHPEF	LENGTH	WIDTH	INTEX	ERF	STREA
303979		0	BND 1569	1318103.480	1317752.332	1321965.134		1105597.6	13.6	13.5	12:11	27.1			80.88				
303980		5	B-16142	1318103.590	1317752.442	1321965.244		1105597.71					39.8 D -0.7ø Left 3.7ø Up						
303981		7	AGM	1318106.200	1317755.052	1321967.854		1105600.32	16.344	10.677	:								
303982	2B-1318111.723-2016-51	16	crack field	1318111.723	1317761	1321973		1105606	21.842	5.121	6:24	26.963	Associated With Dent ID 4901644	8.32451	4.60	2.51	ext		
303983		7	DENT	1318111.872	1317760.724	1321973.526		1105606.15	22.041	4.98	6:00								
303984		2	DENT	1318112.083	1317760.935	1321973.737		1105606.36	22.283	4.782	6:00		DENT						
303985		16	dent	1318112.096	1317760.948	1321973.75		1105606	22.215	4.748	6:12	26.963	Associated With Crack Field ID 4901645		12.03	6.70			
303986		5	D-4579	1318112.153	1317761.005	1321973.807		1105606.06	22.309	4.921			1.1% Dent at 6:00	1.107	14.96				
303987		16	weld	1318116.844	1317765.721	1321978.646		1105611				40.322							



Integrating Multiple ILI Tool Runs

- Reporting thresholds
 - Deformation reporting specifications
 - 1% Deformations
 - False positive challenges <1%
 - Crack reporting specifications
 - Any dent with a crack field reported
 - Limitations with UT tool detection within deformation
 - ◆ Continuing to improve process
 - ◆ **PRCI MD 1-13**
 - Crack data is integrated and reviewed for feature proximity to deformations
 - Crack location and orientation now considered
- Continual review and analysis of crack raw data as data becomes available or is refreshed
 - This review is documented and integrated into the DRRPM
 - DRRPM scores are updated

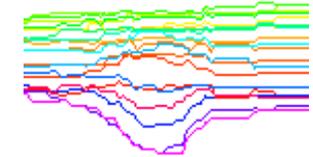
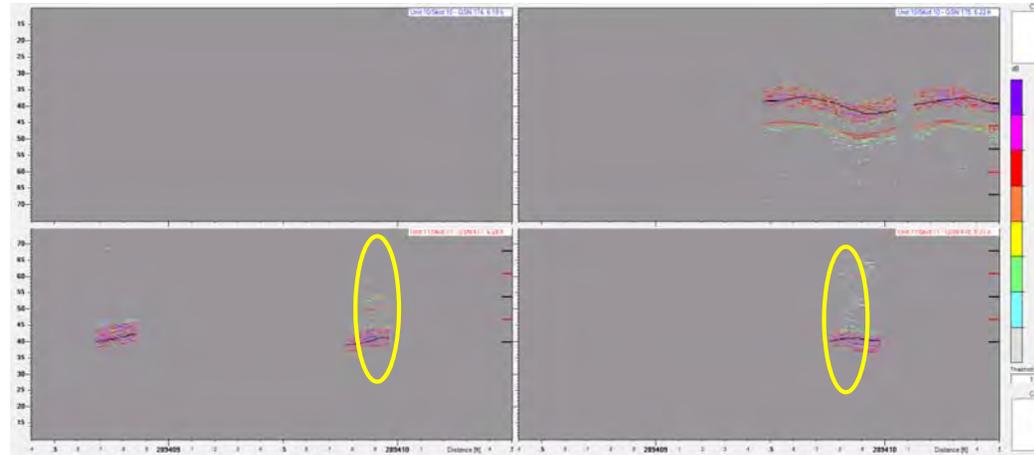


Integrating Multiple ILI Tool Runs

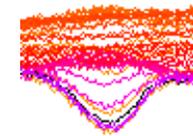
Looking for the unreported\below threshold

2014 UT ILI

- Single reflector only
- Only CCW
- Not seen on skip
- Weak signal



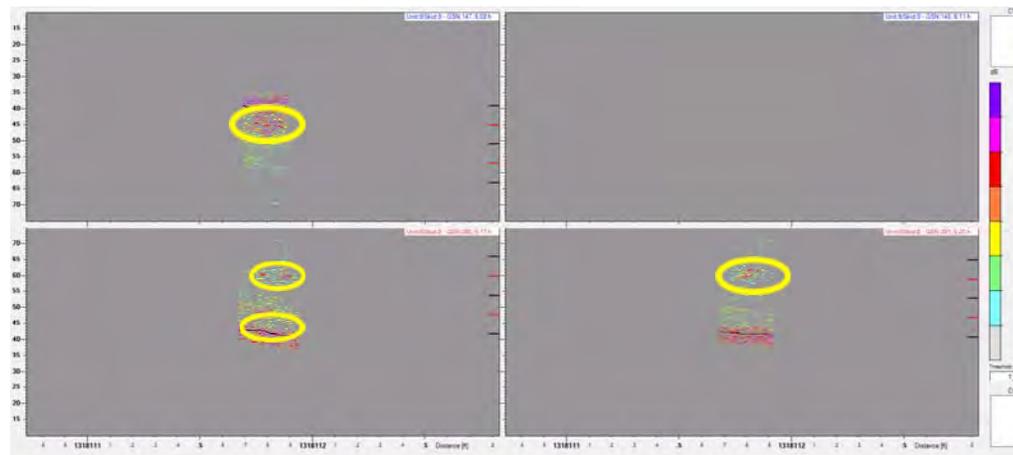
2003 DEF



2013 DEF

2015 UT ILI

- Multiple reflectors present
- CW\CCW
- Seen on ultrasonic skip
- Strong signal
- Called crack by ILI



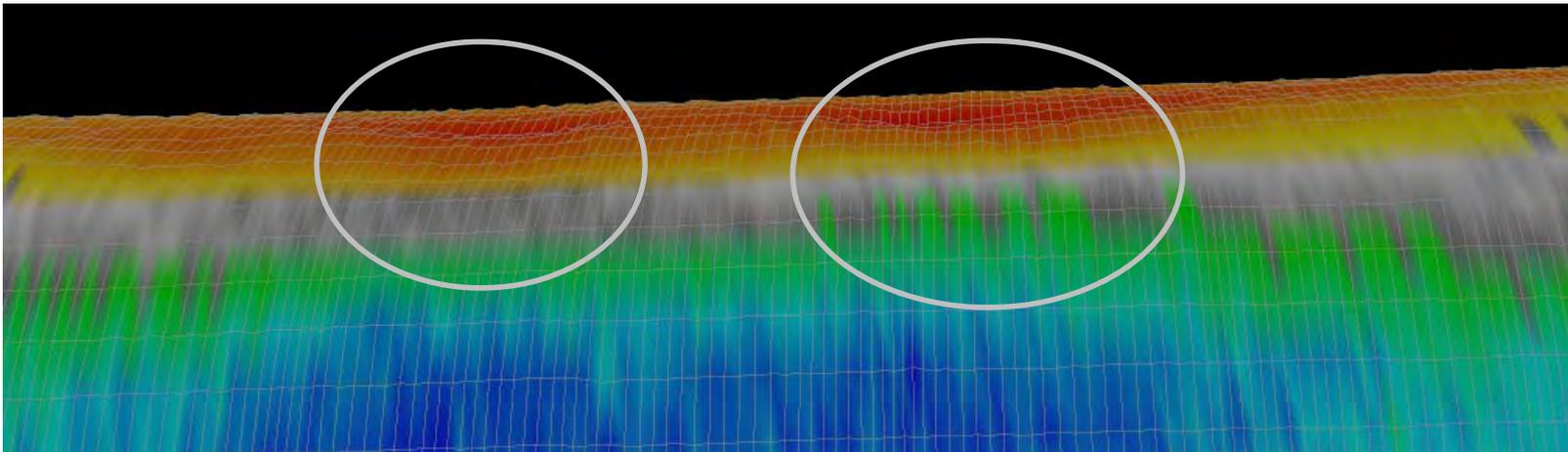
2016 Excavation

 Reflectors



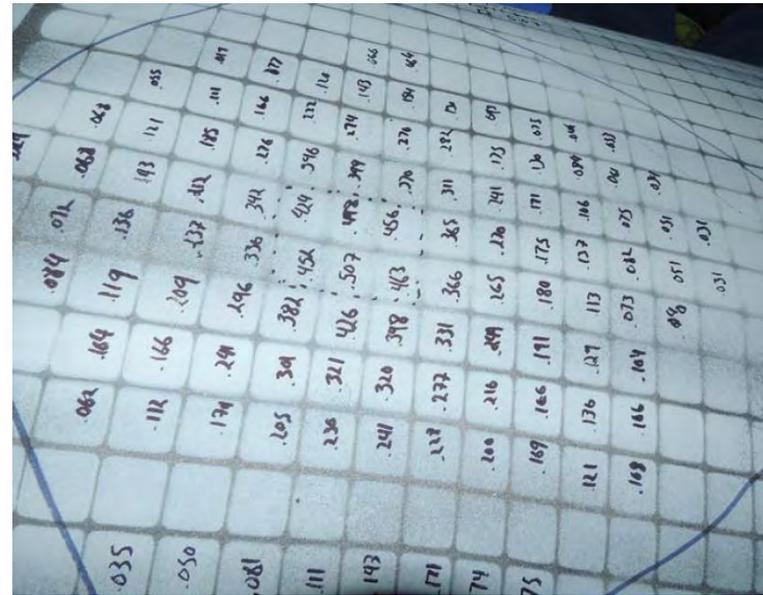
Effects of Dent Shape

- Multi peak dents vs single peak

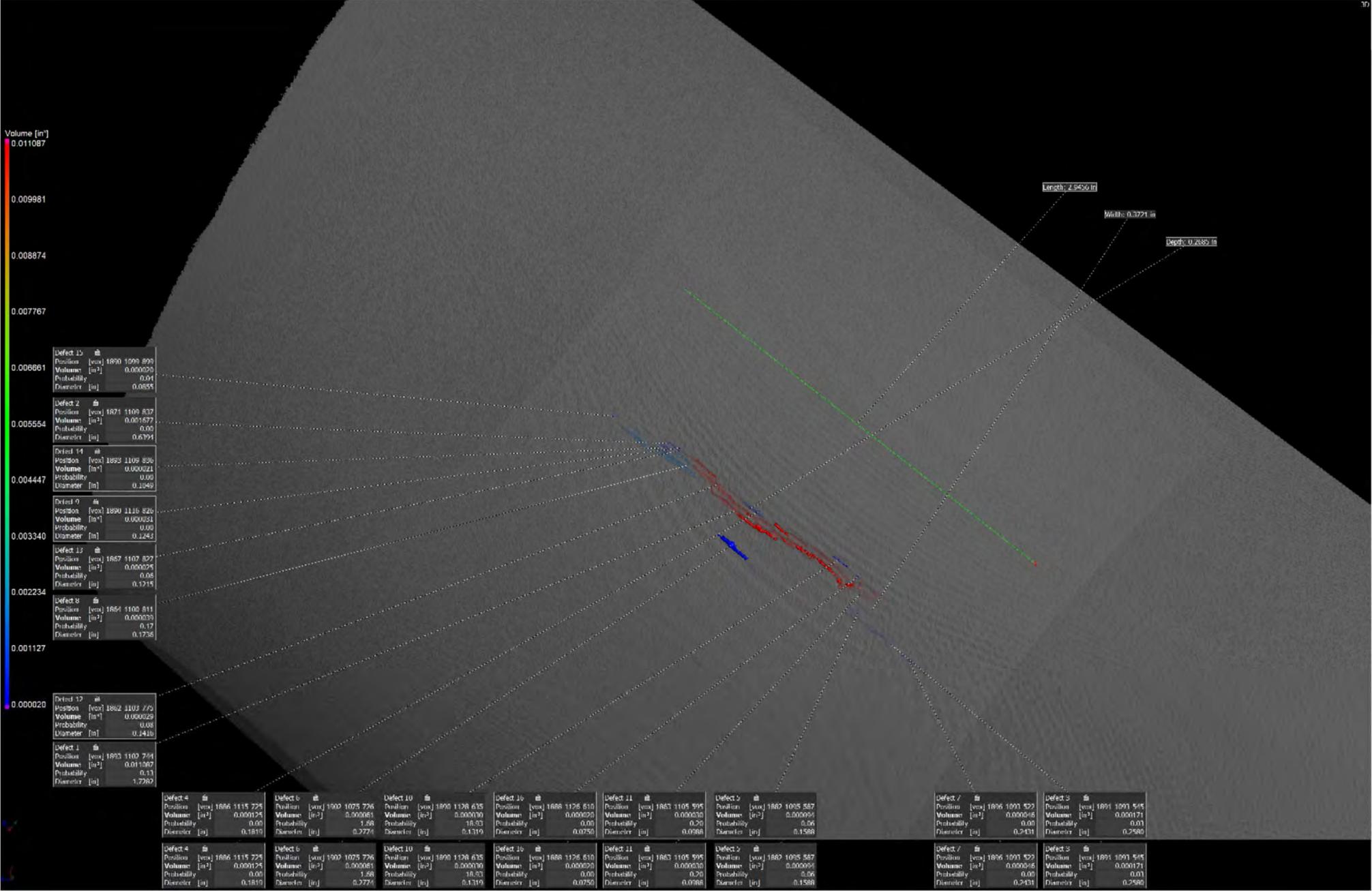


NDE Methods – Dents and Cracks

- Document deformation profile in grid system
 - Minimum grid points
 - Deepest & most prominent locations
- Magnetic Particle dent and 12" surrounding
- Cracks are sized using shear wave or phased array – **internal cracks**
- If no findings during MP, shear wave or phased array
- 3D scan/profile
 - Compare to ILI – SP and RP
- NDE research
 - Multiple NDE vendors sizing cracks, destructive testing for confirmation
 - PRCI MD 1-13



NDE Methods – Dents and Cracks



Key Findings and Lessons Learned

- **The dent fatigue “iron triangle”:**
 - **Pressure cycling**
 - **Restraint condition (predictable by shape)**
 - **Dent shape – key parameter, dictates local stresses and strains, affect stress magnification**
- **Dent fatigue results in tight cracks**
 - **Leak vs rupture (liquids view) – affects excavation locations, consequence models**
 - **Low release volumes at low pressures, cycling effects, pressure attenuation - discharge vs suction**
 - **Crack mouth opening and frictional forces**
- **Pressure cycling fatigue vs. corrosion fatigue & SCC**
 - **Different mechanisms**
 - **Different assessment, response/repair**
 - **Field inspection and documentation**



Key Findings and Lessons Learned

- **Improvements in inspection technology and refinements of engineering assessment methods needed (PRCI MD and Crack Management)**
- **Not all stress risers in dents need immediate response**
 - Dents/deformations with welds and corrosion can be managed
 - Dents/deformations with fatigue cracks – more research needed
- **Diligence in the ditch – accurate dent profile and fatigue cracking measurement are needed**
- **Better study of crack growth during pressure cycling**
...and what the ILI and NDE technologies can provide the help with improved integrity management
- **Impacts of pipe flexing during cycling on repair**

Avoiding Duplication - Ongoing Projects

Collecting and extending what we know and filling in gaps

PRCI

- Full scale testing of dents on real corrosion features (PRCI MD-4-14)
 - Full scale testing of shallow (<2%) restrained dents
 - Extend dent assessment model to dents interacting with corrosion (updating MD 4-9)
 - Development of alternate code requirements for dent acceptance or call for remedial actions (PRCI MD-4-13, API RP 1183)
 - Review of automated ILI shape parameter measurements
 - ILI pull trials to demonstrate the ability of current systems
 - Characterize dent shape
 - Size cracks in dent
- ↓
- Identify cracks in a dent
 - Destructive Testing of samples

R&D Projects for Consideration

Data Mining of Excavated Dents

- Leverage operator data and excavations completed to date to better understand KPVs
- Develop dent fatigue screening tool for single peak features
- Dent Feature Shape Factor Evaluation - PRCI Level 2 assessment based upon detailed ILI characterization and operational line pressure characterization (5500 dents)
- Level 1, Level 2, and Level 3 analysis, as appropriate, of 2016 and 2017 DRRPM dents
- Work with other operators on available data and dissect it
- Dent Sample Creation For ILI And NDE Training And Evaluation – includes creation of up to 20 dent features
 - Include dents on laminations, part wall ID and OD cracks, dents with cracks, dents with range of corrosion (extension of MD 1-13)

R&D Projects for Consideration

ILI Improvements

- Demonstrate ILI Tool Capability
 - Plain dent shape
 - Definition of ILI dent shape measurement accuracy requirements
 - Corrosion identification and characterization on dent
 - Crack identification and characterization on dent
 - Corrosion & crack identification and characterization on dent or closely aligned near dent
 - Distinguishing forms of metal loss (corrosion vs gouge)
- Distinguishing ID vs OD cracking

R&D Projects for Consideration

ILI Improvements

- Commonality in Dent ILI treatment
 - Updates to 1163 in terminology and characterization
 - Some of this will be addressed in API 1183
 - What is not a dent
 - Technical basis for sorting wall deformation features (e.g. dent, ovality, ripple, wrinkle buckle)
- ILI Dent Damage Accumulation Measurement
 - Can we infer / measure dent strain (not from dent shape)
 - Can we infer / measure dent fatigue damage accumulation

R&D Projects for Consideration

NDE

- Further evaluate Computed Tomography for crack detection and development of industry crack reference standards
- Dent damage accumulation measurements
 - Can we infer / measure (not just detect) dent strain (not from dent shape) and convert this to meaningful data
 - Can we infer / measure dent fatigue damage accumulation
 - These measurements are the precursor to
 - New ILI integrity management tools
 - Differentiating gouges and corrosion

R&D Projects for Consideration

Other issues

- Calibrate Semi- Quantitative Risk Ranking Tools
 - What parameters are important and how much weight should be applied to each
- Collect and infer importance from data base analysis and field observations
- Effects of material properties and toughness
 - Measure during full-scale testing
- Do we need more data on D/t to support off ramps?