REX2024
PRCI Research Exchange

PRCI-REX2024-081: Performance of ILI Technologies for Dents with Interacting Features (NDE-4-18)

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PRCI LEADING PIPELINE RESEARCH
Pipeline Research Council International

Trial Protocol

- Introduction
- Sample Production and Characterization
- Trial Protocol
- Trial Observations
  - Dents
  - Corrosion
  - Gouges
  - Cracks
- Concluding Remarks

Introduction

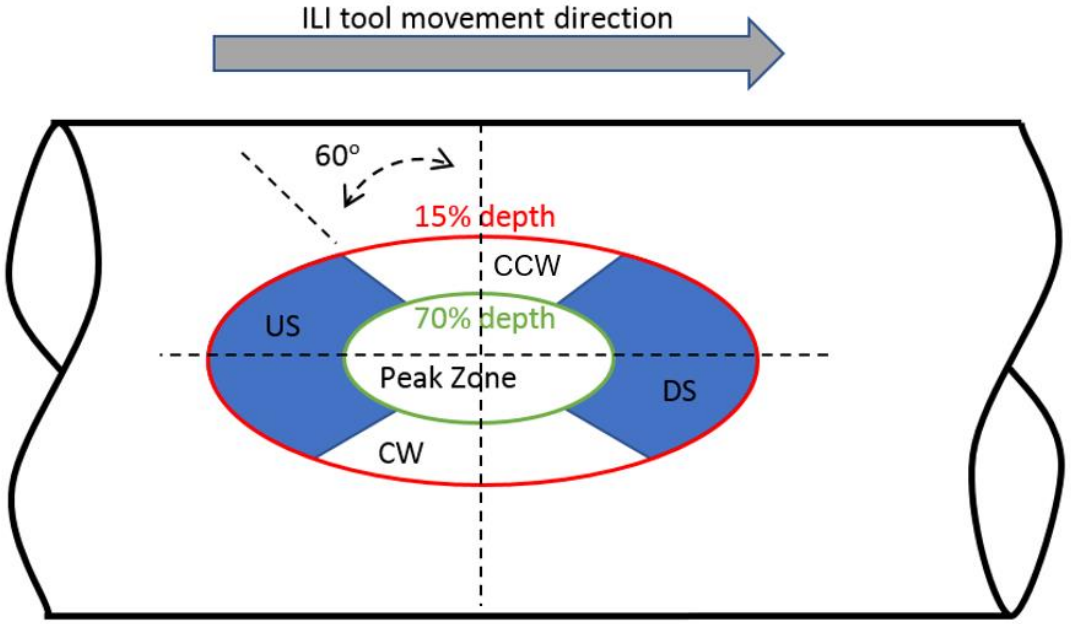
- **This is an overview of the PRCI NDE-4-18 project, part of the PRCI MD SRP**
  - To support industry drive for integrity management improvement
  - 1st set of trials were sponsored by PRCI. The 2nd set of trials were cosponsored PRCI-PHMSA
  - 7 ILI service providers (ISP) participated in the 1st trials. 4 ISPs participated in the 2nd trials.
  - Trials to consider ILI performance for mechanical damage (dents) with coincident features (corrosion, gouge, weld, crack). More pipe specimens were added for the 2nd trials.
  - Considered a range of ILI technologies and systems
- **The objectives were to**
  - Prepare and characterize pipe samples with dents and coincident features
  - Demonstrate performance of ILI technologies w.r.t feature detection, identification and sizing
  - Provide feedback and reference data to Service Providers for system and specification development

Sample Production and Characterization

- **Trial Samples and Features**
  - Focus on 20 inch diameter (ERW / DSAW) pipe
    - 0.281 to 0.5 in wall thickness
  - Features in trials identified as
    - Dent
    - Corrosion in plain pipe . . . . . All corrosion features from
    - Dent with corrosion pipe removed from Service
    - Dent with gouge
    - Dent on welds
    - Dent with cracks . . . . . All dents and crack fabricated
    - Dent with corrosion and cracks through lab cyclic pressure loading
    - Dents on welds and cracks
  - 1st Trials - Approx. 500 ft of pipe with 75 pipe segments w/ dents w/wo coincident features and 11 pipes segments w/o dents.
  - 2nd Trials – Approx. 1000 ft of pipe with 134 pipe segments w/ dents w/wo coincident features and 20 pipe segments w/o dents.
  - In total 158 pipe segments were used for the trials.

Trial Protocol

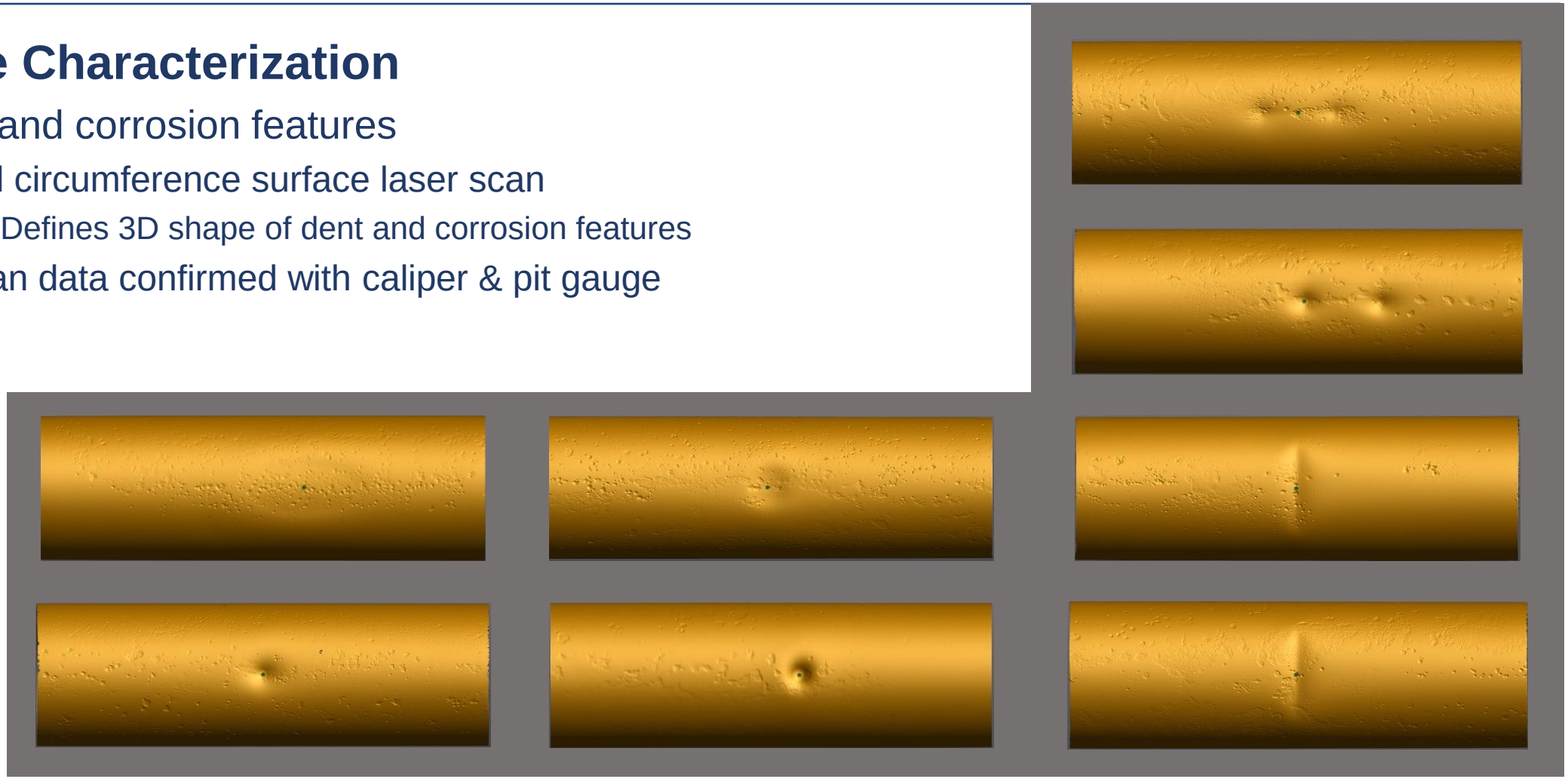
- **Document developed describing the trial process**
  - Two repetitions of five test speeds (1.1, 3.3, 5.6, 7.8 & 11.1 mph for pull trials and 1, 1.5, 1.8, 2 & 4 mph for liquid coupled trials)
- **Define feature specific data reporting**
  - Eight specific features types defined
    - Corrosion
    - Corrosion in dent
    - Crack in corrosion in dent
    - Dent on weld
    - Dent
    - Crack in dent
    - Gouge in dent
    - Dent on weld with crack
  - Characteristics of each feature and position defined relative to reference mark
  - Dent coincidence zones defined
  - POD and POI defined as in API 1163



- **Trials completed for 9 ILI Service Providers**

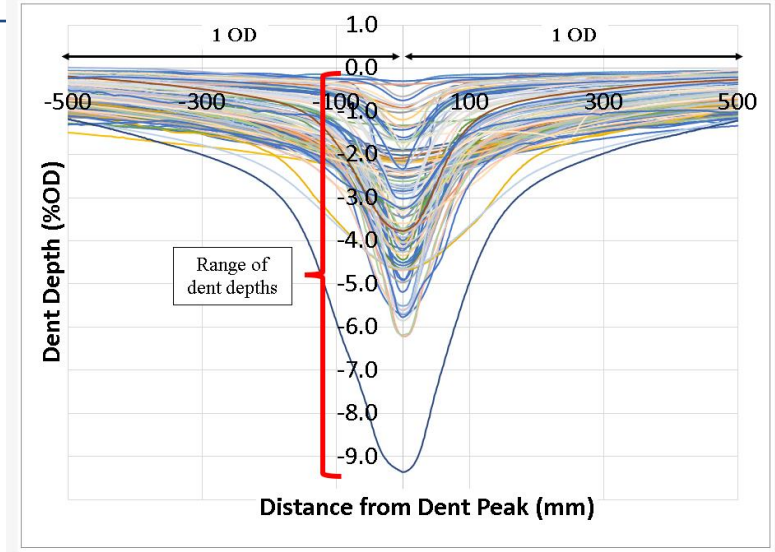
Sample Production and Characterization

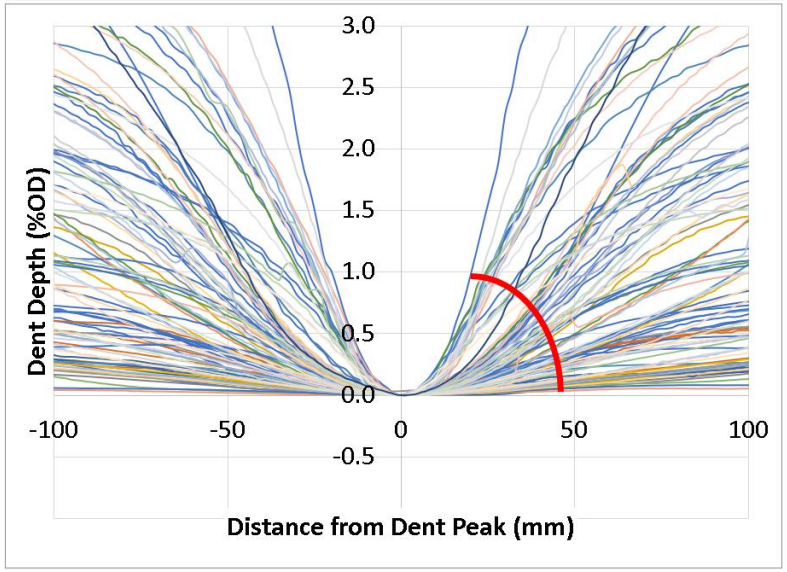
- **Sample Characterization**
  - Dent and corrosion features
    - Full circumference surface laser scan
      - Defines 3D shape of dent and corrosion features
    - Scan data confirmed with caliper & pit gauge



Sample Production and Characterization

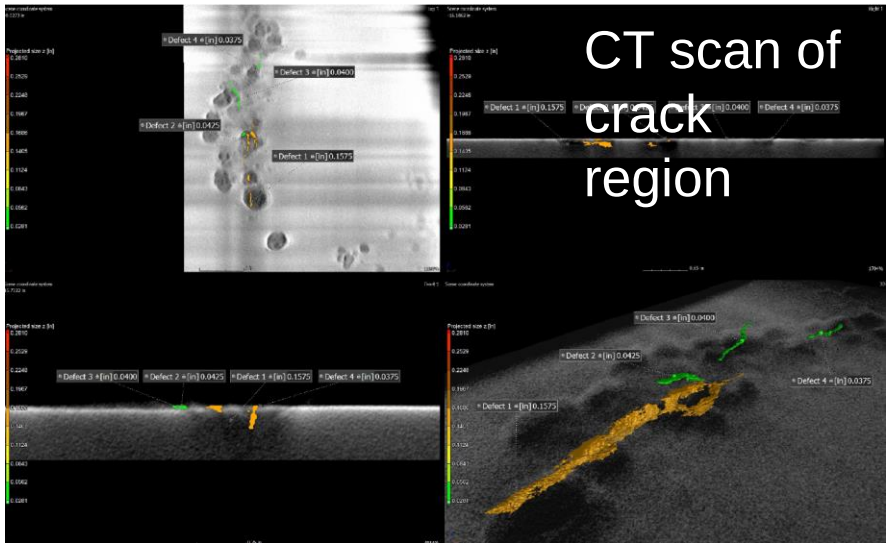
- **Range of Corrosion Features**
  - Depth from 10 to 55% depth
  - Cover all POF 100 classes
    - Pin-hole, Pit, Axial / Circ. Groove, Axial / Circ. Slotting, General
- **Range of Dent Feature Shapes**
  - Single and multi-peak dents with depths from 0.4% to 9% of pipe dia.
  - Dents created with various indenters with pipe unpressurized and pressurized

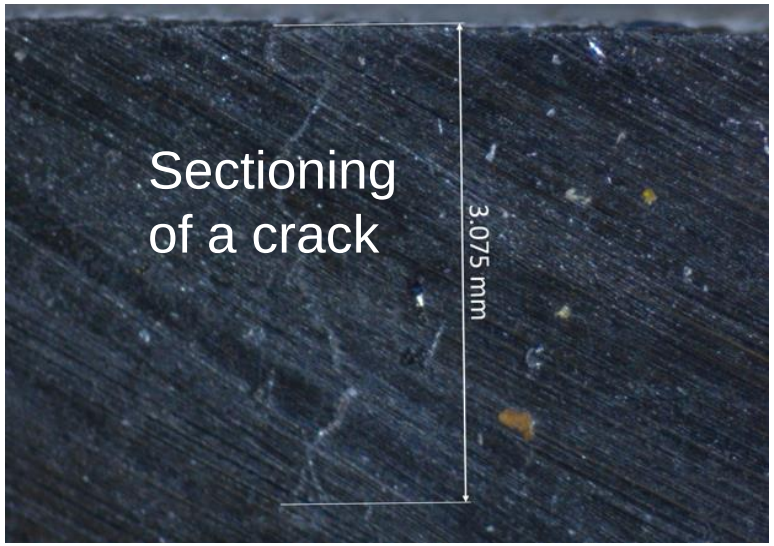


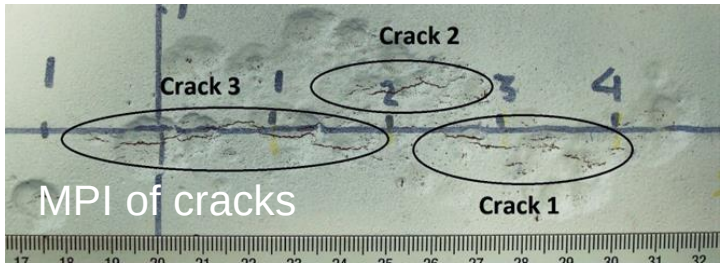


Sample Production and Characterization

- **Sample Characterization**
  - Crack features
    - Characterized digitally after magnetic particle inspection (MPI)
      - Defines surface length and position of features
    - Metallurgical sectioning and Computed Tomography (CT) used to augment crack depth and shape for a subset of features







Trial Observations – Detection of Dents

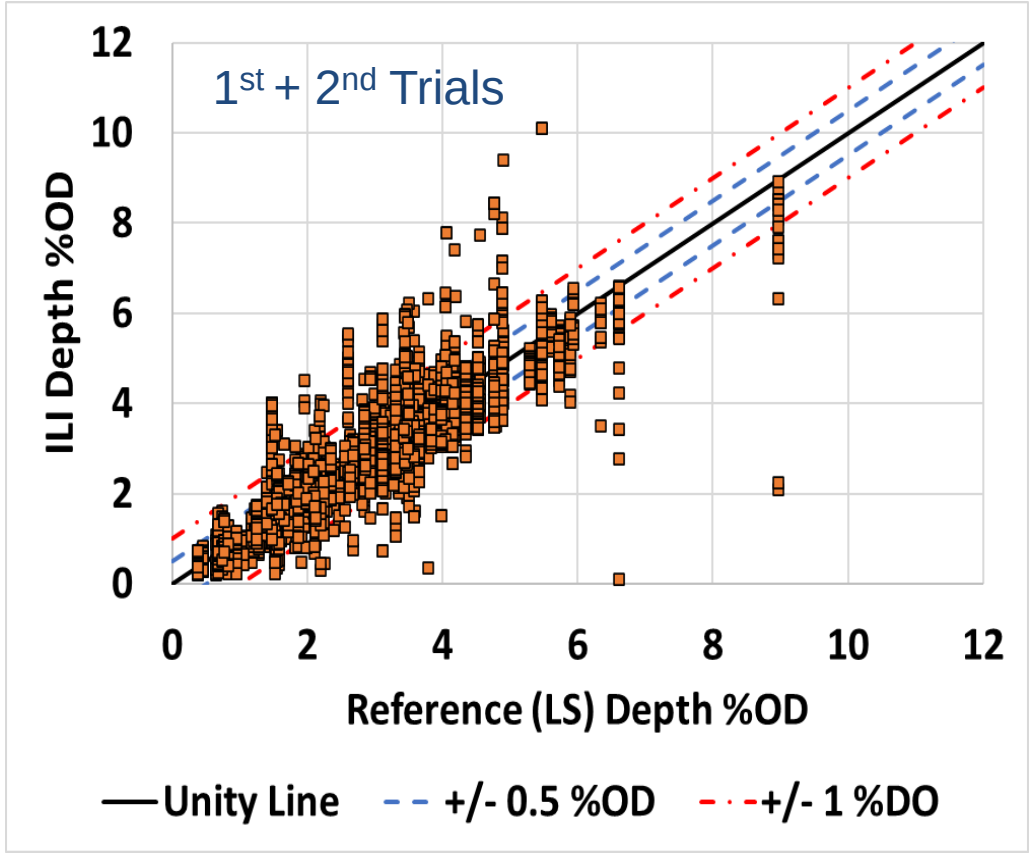
- Probability of detection of dents for all ISP in 1st and 2nd trials
- Overall, dent POD are high for all ISPs

1st Trials			
ILI Service Provider #	True Positives	True Positives + False Negatives	POD
1	523	530	0.99
2	530	530	1
3	168	265	0.63
4	416	424	0.98
5	530	530	1
6	515	530	0.97
7	518	530	0.98

2nd Trials			
ILI Service Provider #	True Positives	True Positives + False Negatives	POD
4	141	145	0.97
5	1420	1450	0.98
8	123	145	0.85
9	1380	1420	0.97

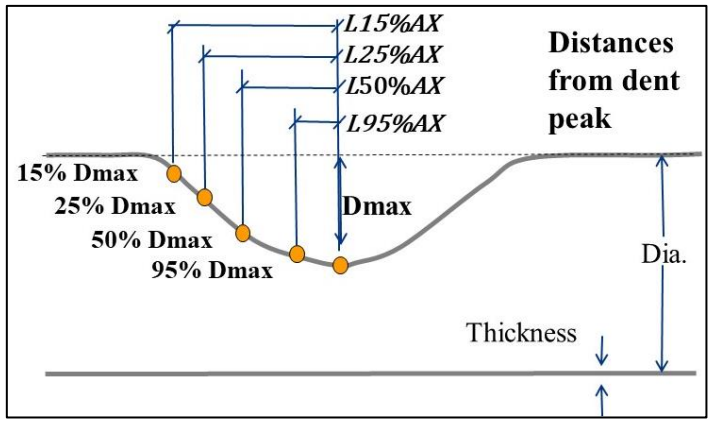
Trial Observations – Dent Depth

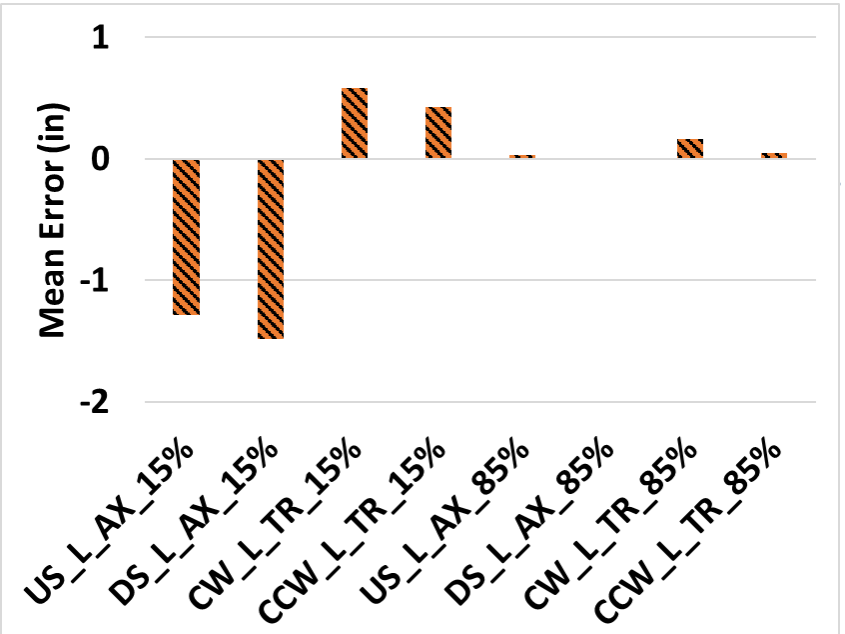
- **Dent depth unity plot performance for all tests of 7 mechanical caliper and 2 ultrasound ILI systems across two trials**
  - Approx ~7,000 observations
  - Good overall performance
  - 95% of data within +/- %1 OD of reference
  - Small bias towards calling lower depths

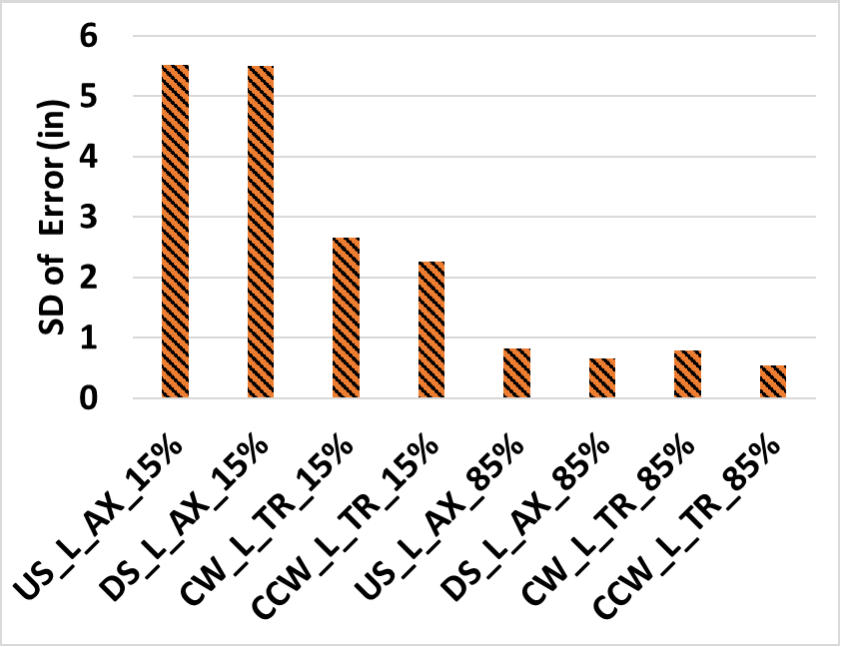


Trial Observations – Dent Shape

- Dent characteristic length/area variation statistics charts for all ILI systems from 1st and 2nd trials
- Mean and standard deviation of variation from reference values have been provided.
- Good overall performance .
- More bias and variation at dent shoulder (<15% of max depth), with reduced values close to the peak.
- CW and CCW results are similar.

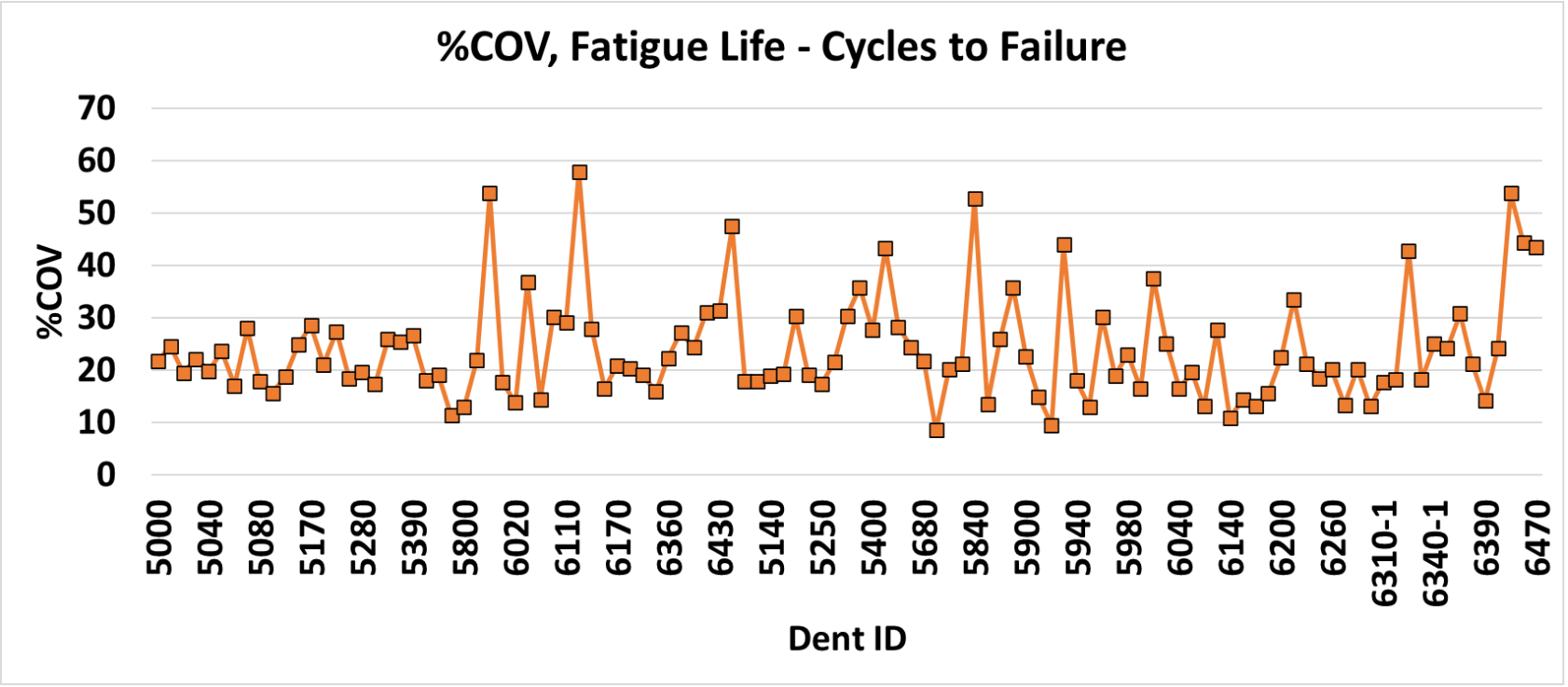






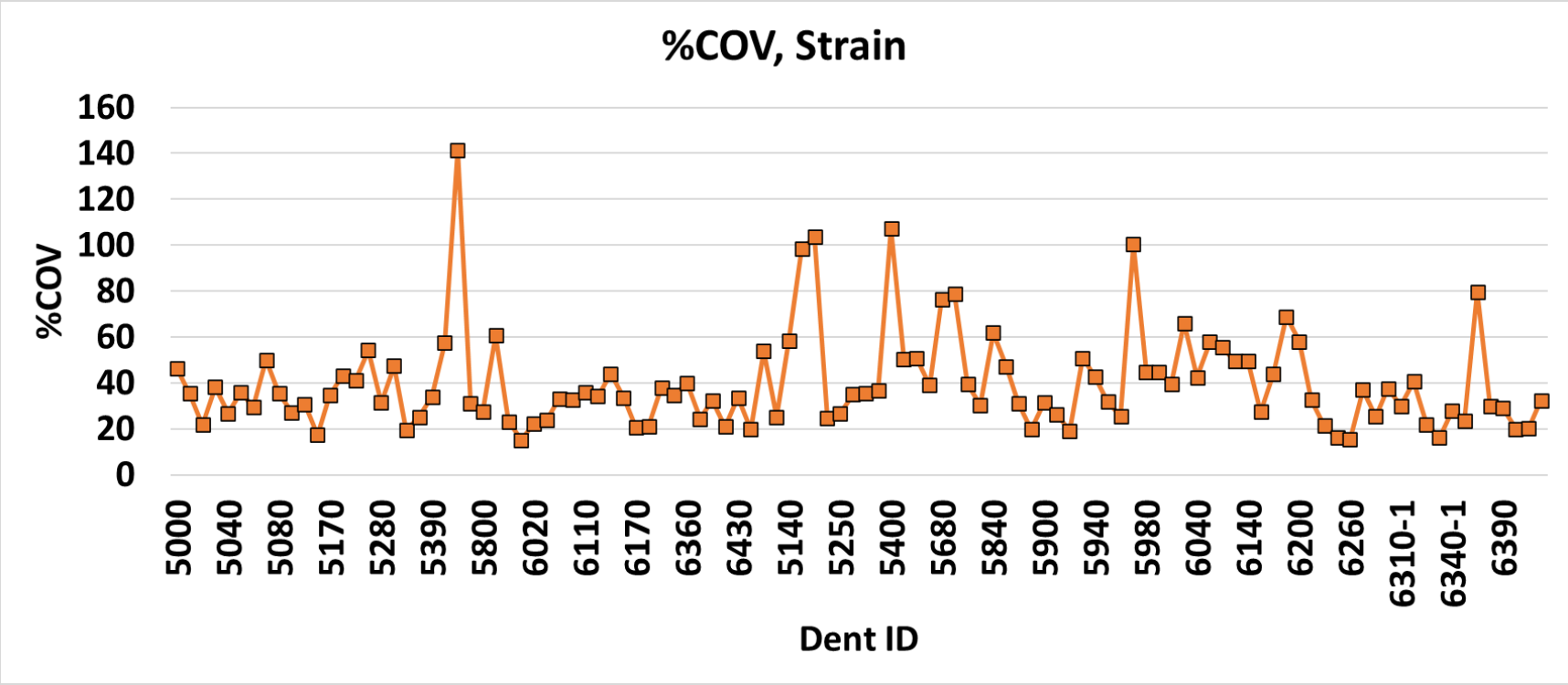
Trial Observations – Dent Fatigue Life

- Considered run to run variation based on ILI caliper data for all ILI systems
- Dent Fatigue Life Calculated for reference and ILI data using API 1183 shape parameter approach with 13ksi (90 MPa) pressure cycles
- Generally, %COV of fatigue life <30%.



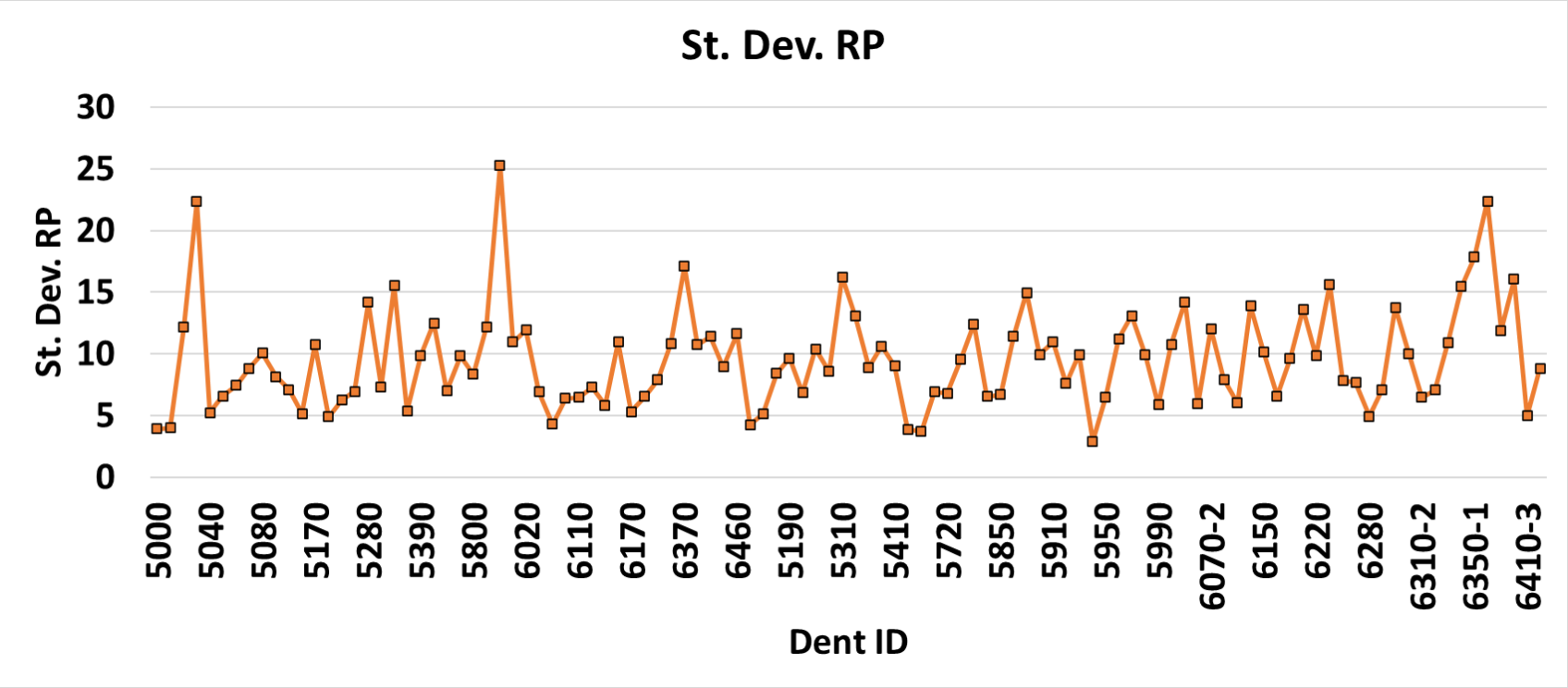
Trial Observations – Dent Strain

- Considered run to run variation based on ILI caliper data for all ILI systems
- Strain calculated for reference and ILI data using ASME B31.8 Appendix R
- Generally, %COV of strain <40%.



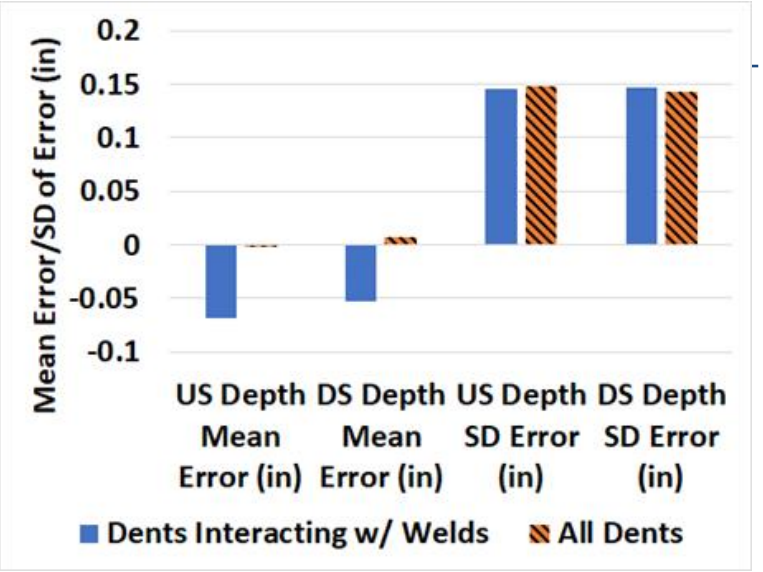
Trial Observations – Restraint Parameter

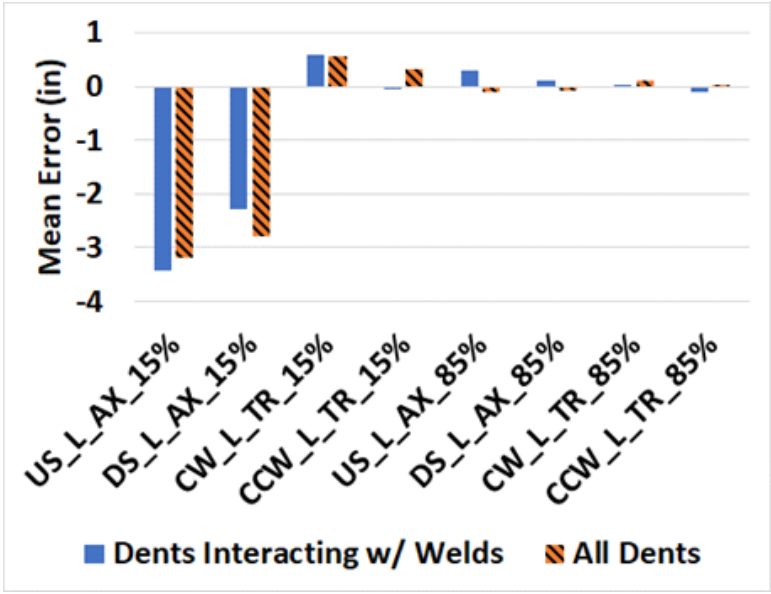
- Considered run to run variation based on ILI data for all ILI systems
- Calculated using restraint parameter formulation from API 1183
- Generally, St. Dev. Of RP < 10

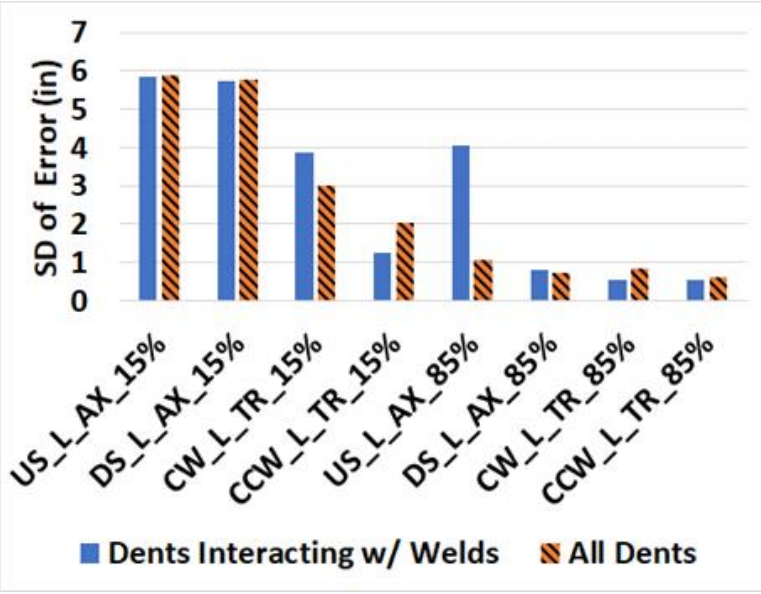


Trial Observations – Dents on Welds

- 20 dents on weld were present - 14 long seam welds and 6 girth welds
- Aggregated sizing performance of dents on welds for all ILI systems, compared with set of all dents.
- Overall, presence of weld did not significantly affect performance

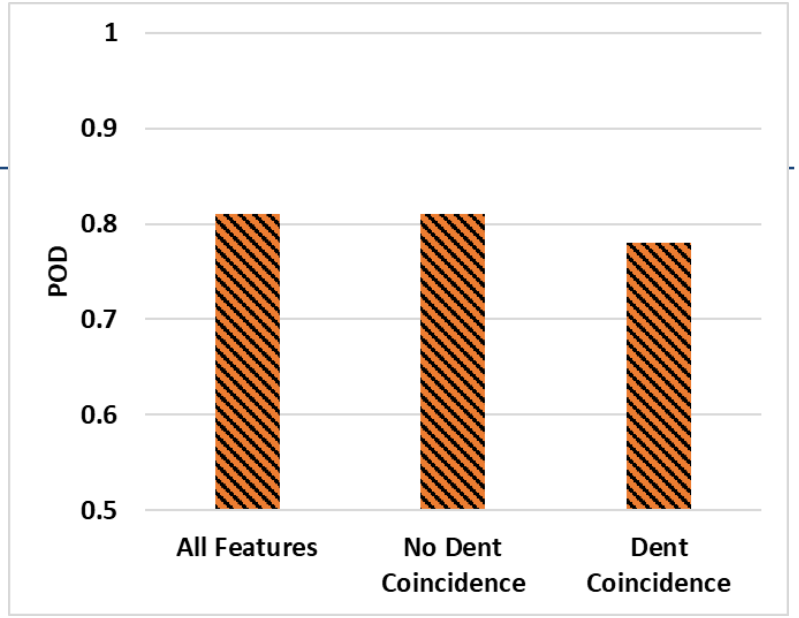


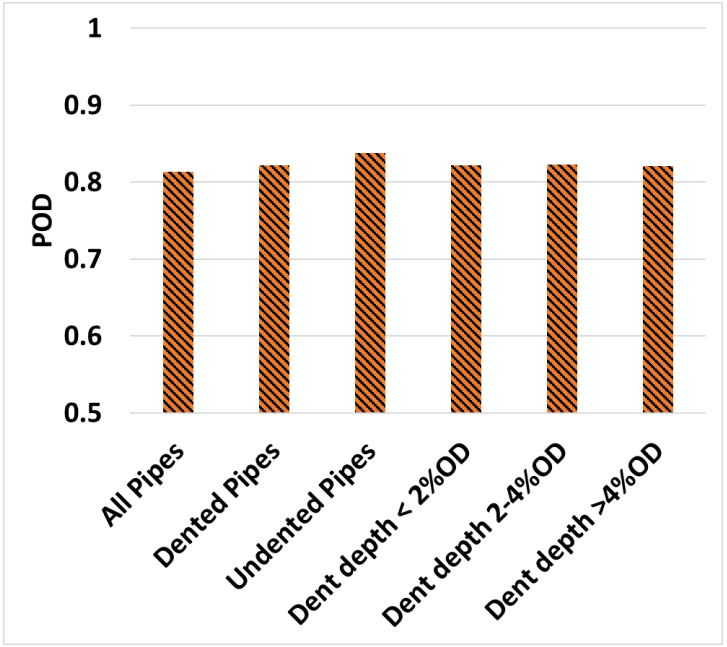


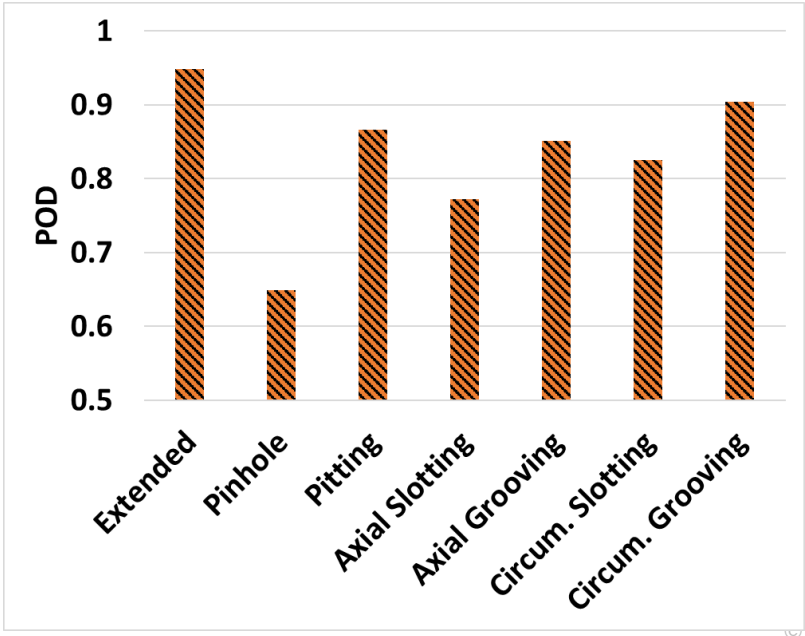


Trial Observations – Corrosion

- Aggregate corrosion detection performance of all ISP in 1st and 2nd trials.
- Overall, PODs are high, >80%.
- Overall, POD for features not coincident with dent were slightly higher.
- Similar POD for dented and undented pipes.
- Similar POD across dented pipes with different dent depths.
- POD lower for corrosion features coincident with dent peak zone.
- Small features like pinhole and slotting exhibit low POD.

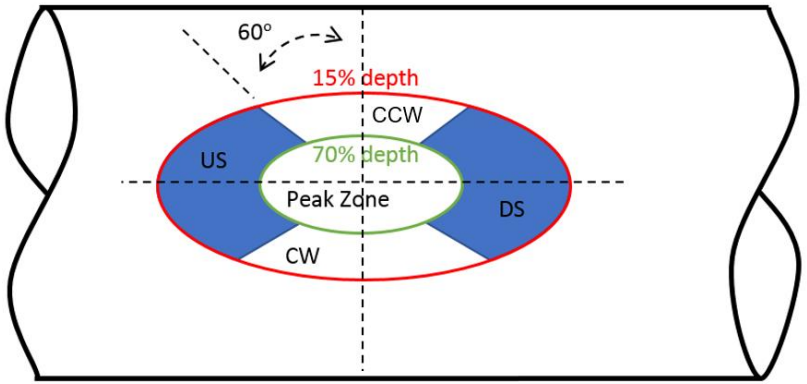


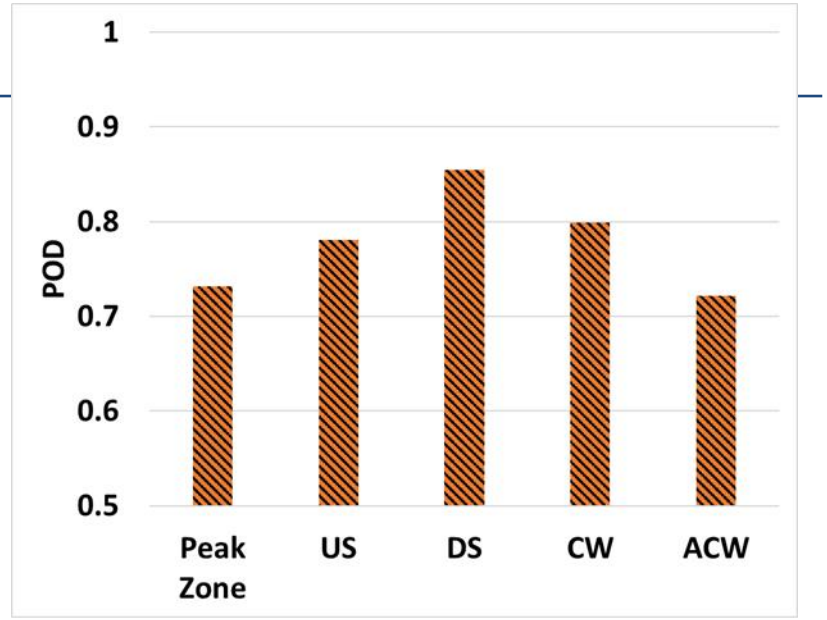


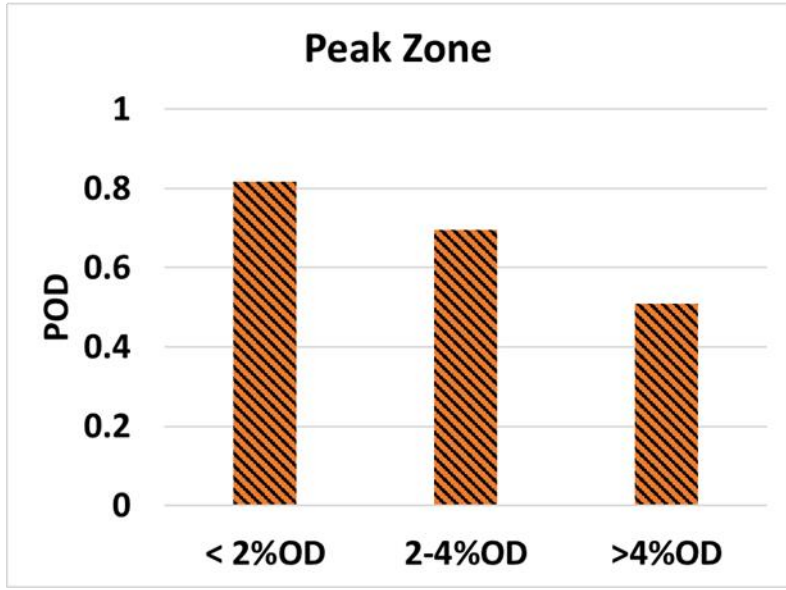


Trial Observations – Corrosion

- Effect of corrosion feature location in dent on POD
- Overall, small impact (peak zone most affected)
- Significant reduction in POD is observed for features at peak zone with increase in dent depth

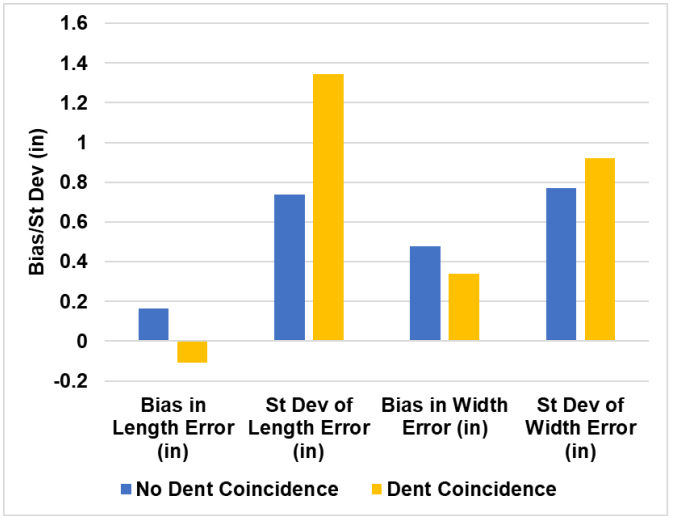


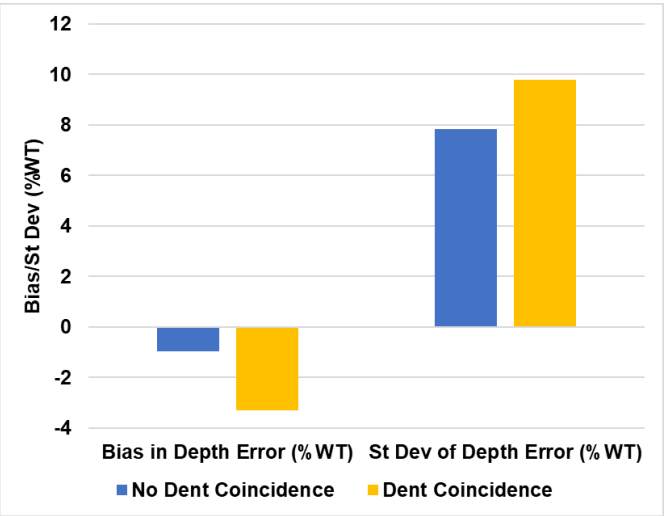




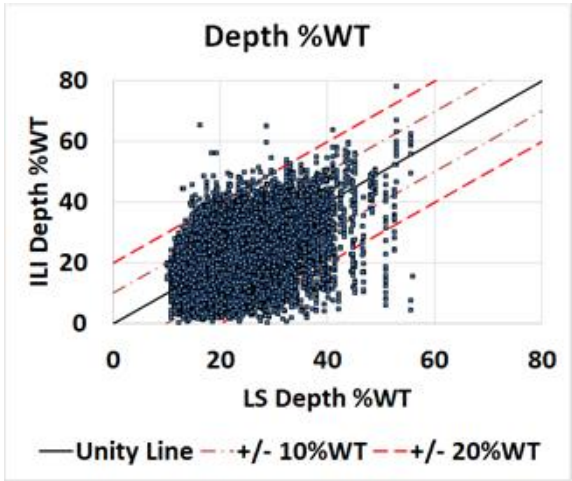
Trial Observations – Corrosion

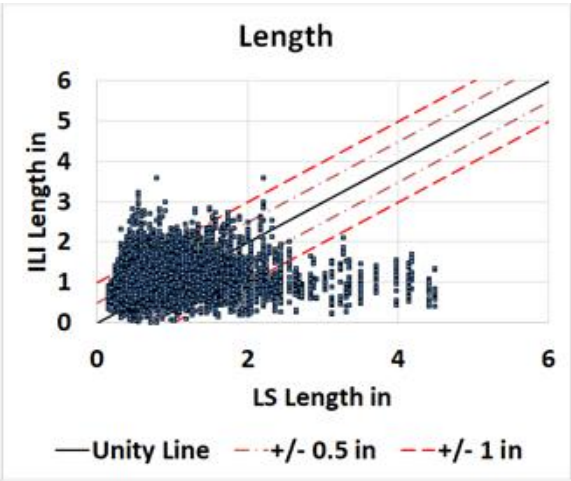
- Aggregated sizing statistics for all ILI systems presented here.
- Bias and St Dev of sizing errors of features not coincident with dents were lower compared to features with dent coincidence.
- Good overall performance on depth
- Small bias underestimating feature depth
- Bias to underestimate length of long features
- Bias overestimate width of features

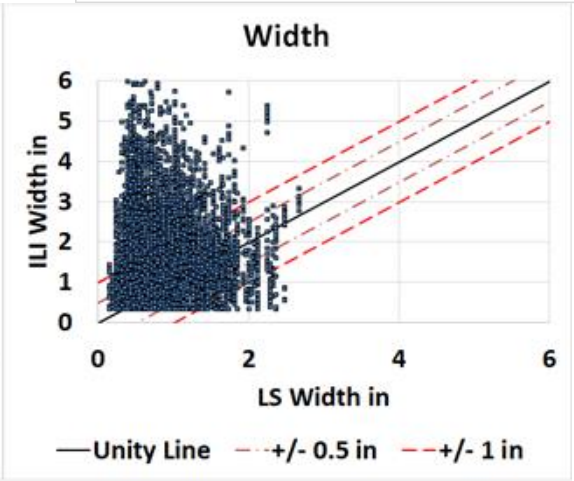




Typical sizing trends – ISP #5 Unity Plots

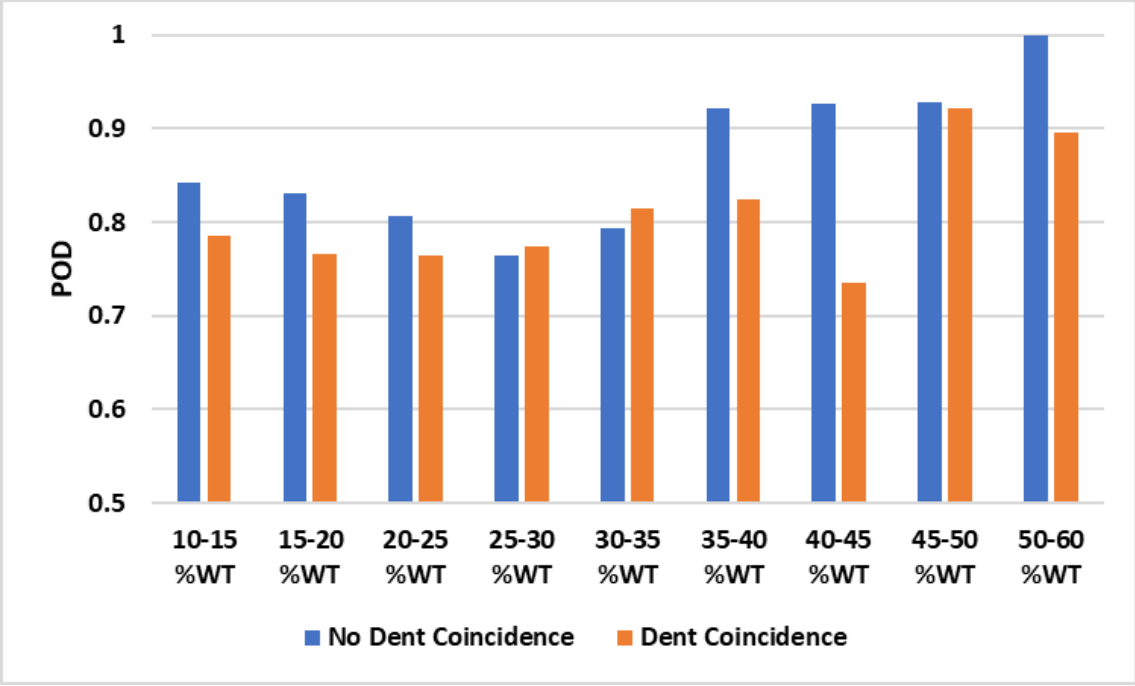


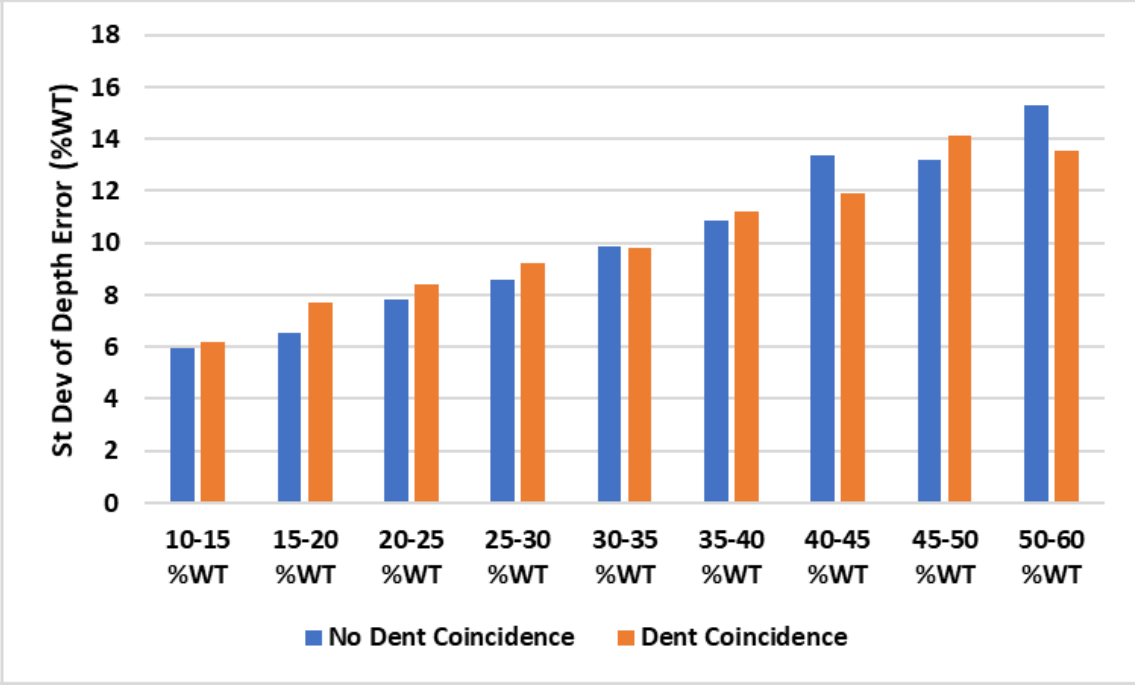




Trial Observations – Corrosion

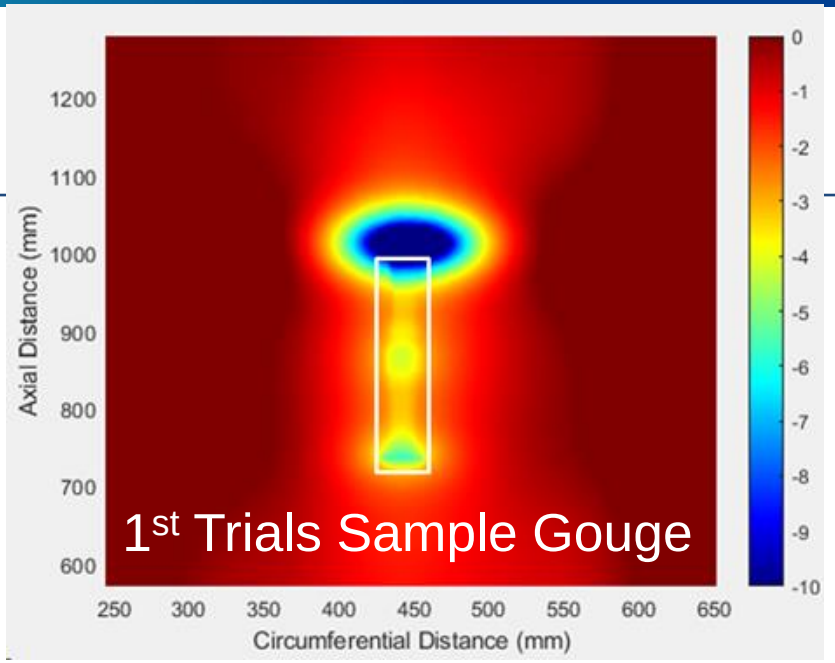
- **Detection and sizing based on corrosion depth**
  - Overall, POD slightly higher for features not coincident with dents across all corrosion depth bins. POD higher for deeper features.
  - Similar depth sizing variation across the corrosion depths for features with and without dent coincidence. Variation in depth sizing increases with depth.





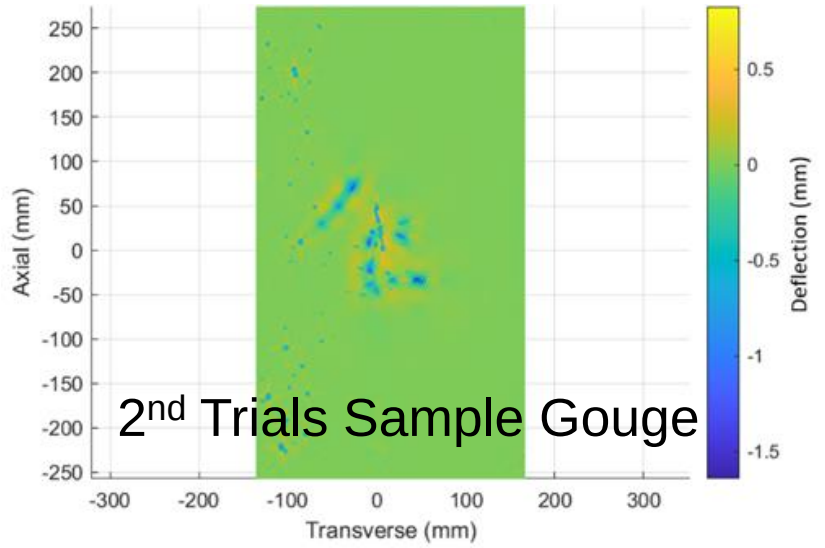
Trial Observations – Gouges

- **Effect performance on small pool of gouges**
  - 21 Simulated – backhoe tooth formed
  - 5 Machined – dented & machined
- **For the 9 ISPs**
  - Generally, simulated gouges had high POD >80% in 1st trials
  - POD overall lower for 2nd trials due to addition of more complex shaped gouges
- **On average 5 false gouge calls were made by the ISPs**



1st Trials	Simulated Gouges	
ILI Service Provider #	POD	Avg. False Gouge Calls Per Tool Run
1	1	3
2	0.97	14
3	0.93	6
4	0.83	1
5	0.83	2
6	0.53	2
7	0.83	0

2nd Trials	Simulated Gouges	
ILI Service Provider #	POD	Avg. False Gouge Calls Per Tool Run
5	0.78	14
8	0.78	5
9	0.73	4



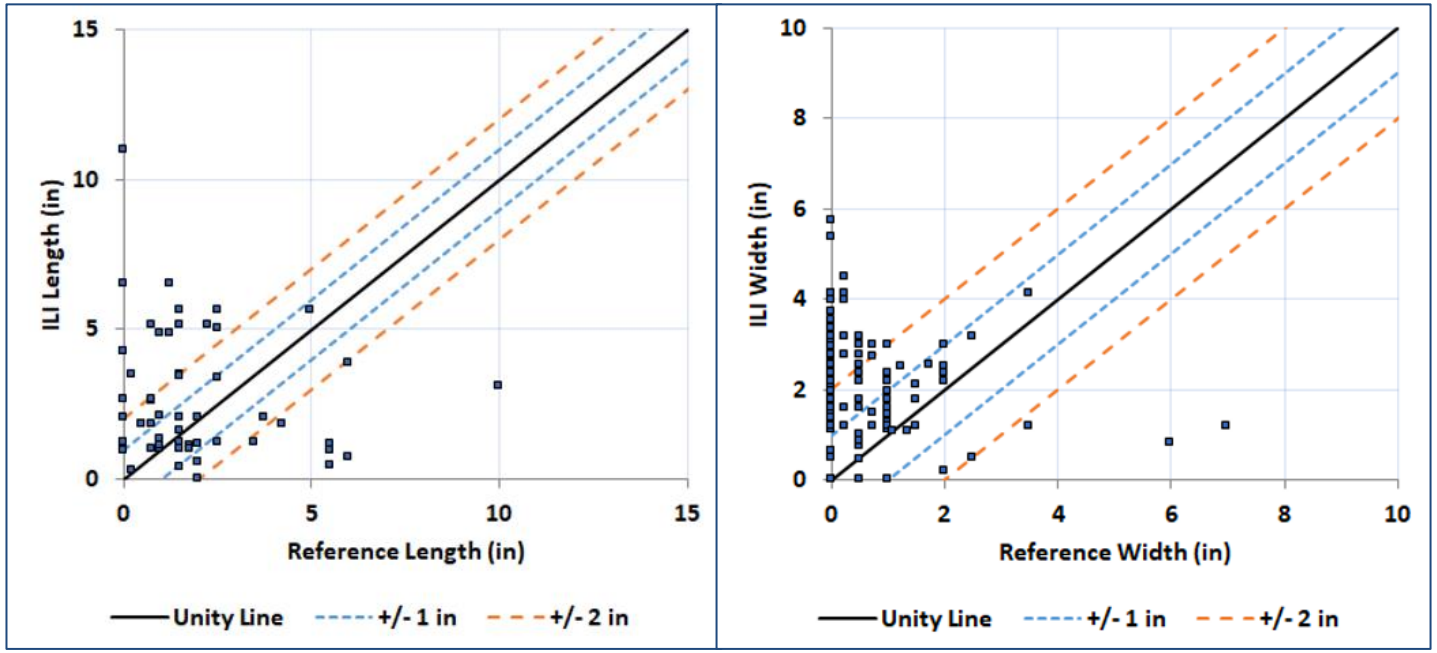
Trial Observations – Cracks

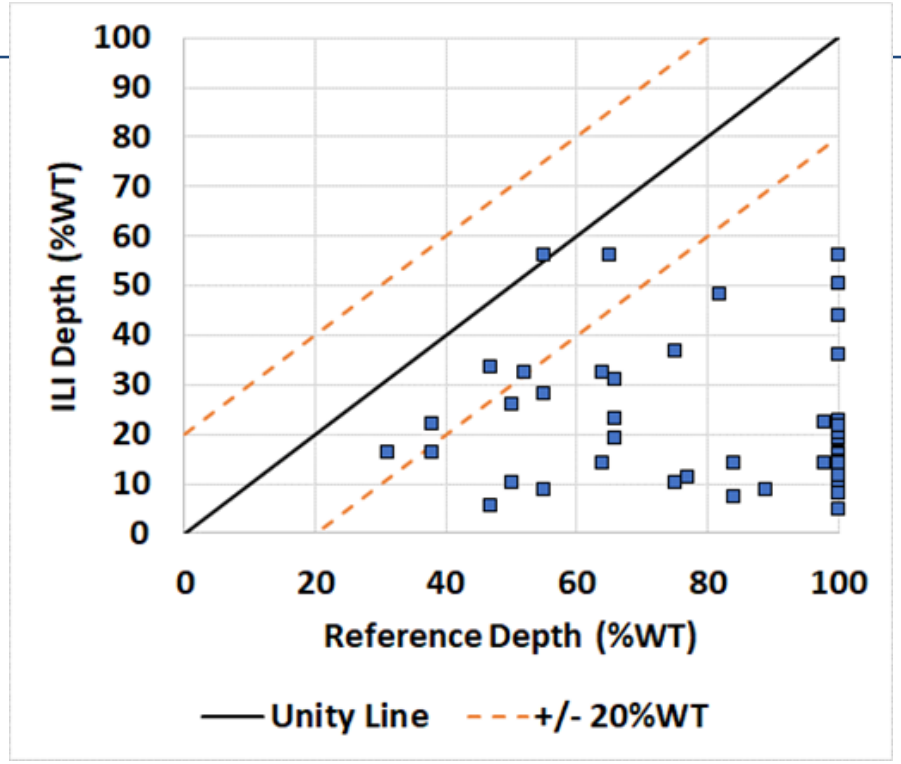
- 2 Ultrasonic ILI tools participated in trials
- All crack features coincident with dent, some features in corrosion
- 1st trials had 55 cracks on dents and 2nd trials had 107 cracks on dents.
- 1st trials POD higher than 2nd trials PODs.
- Overall, 2nd trials had fewer false crack calls.
- Cracks on welds had higher POD compared to other cracks.

Trial #	ILI Service Provider	Number of Pulls	Avg. False Positives Per Run	True Positive	True Positive + False Negative	POD
1st	4	12	78	452	552	0.82
2nd	4	1	33	79	107	0.74
2nd	8 (Axial Cracks Only)	1	71	49	82	0.6

Trial Observations – Cracks

- The ILI crack length measurements have greater variation than for crack width.
- The depths were significantly underpredicted





Concluding Remarks

- **More work ongoing**
  - Additional ILI performance trials
  - Integrity management program enhancement
    - Performance for Detection, identification and sizing of cracks
    - Catalogue samples at PRCI TDC for re-use
  - Improvement of ILI codes and standards
    - Provide information to support regulatory changes
    - Standards enhancement (e.g. API 1163 and API RP 1183)

Concluding Remarks

- **Current work demonstrates**
  - ILI trial program for mechanical damage with coincident features possible
    - Protocol and assessment procedures are good
    - Some opportunities for improvement
  - Performance of existing technology is good
    - Can detect, identify and size dents and corrosion
    - Can detect and identify gouges and cracks
      - sizing will improve as truth/reference data is shared
    - Shows promise to support fitness for purpose assessment of dents with coincident features
  - Feedback to ILI Service Providers may support enhancements
    - Uniformity in reporting
    - Performance of ILI systems

thank you

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