Operationalization of Mechanical Damage Assessment Technology

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Areas of Discussion

• Why?
  • Find critical defects
  • Avoid unnecessary excavations
  • High reliability

• Background
  • Significant amount of industry research has been completed over the past decade
  • ~ 99% of excavations are stable
PHMSA Reportable Incident Data..

- 2010 to Present

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<th>ILI Survey</th>
<th>Natural Gas</th>
<th>Hazardous Liquid</th>
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<tr>
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<td>Yes</td>
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<td>EXCAVATION DAMAGE BY OPERATOR (FIRST PARTY)</td>
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<td>EXCAVATION DAMAGE BY OPERATOR’S CONTRACTOR (SECOND PARTY)</td>
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</table>

Narrative References "Rock" (Pipe or Weld only) 4 | 5

Now pipelines, SCC has 3 attributes

- Dr. R.N. Parkins
- 9th Symposium on Line Pipe Research (circa 1996)
A lot of work has been done...IPC Papers...

IPC1996-1868: Techniques for Preventing Accidental Damage to Pipelines by Alain Lathon, Samir Akel
IPC1998-2035: Fatigue Curves for Damage Calculations for a Dented and Modified Section of the TransAlaska Pipeline System by Glen R. Stevic, James D. Hart, Bill Flanders
IPC1998-2035: Fatigue Behavior of Line Pipes Subjected to Severe Mechanical Damage by Naoto Hagiwara, Noriaki Oguchi
IPC2000-1868: A Pipeline Dent Assessment Model Considering Localized Effects by A. Dinozviter, A. Bhatia, R. Walker, R. Lazor
IPC2000-2056: Multiple Magnetization Level MFL for Pipeline Mechanical Damage Characterization by T. A. Babanok, J. B. Westerhoff, R. J. Zunis, Harvey Haines
IPC2002-27069: An Experimental Approach to Evaluate the Resistance of Gas Pipeline to Dent and Gouge Damage by an Excavator by Gianluca Mannucci, Mauro Giugnielli, Osvaldo Vitorelli and Carlo Spinelli
IPC2002-27122: Basis of the New Criteria in ASME B31.8 for Prioritization and Repair of Mechanical Damage by M. J. Rosenfeld, John W. Pepper and Keith Lewis
IPC2002-27152: Reliability-Based Limit States Design for Onshore Pipelines by Maher Nessim, Tom Ziemerjan, Alan Goyer, Martin McLamb, Brian Rothwell and Joe Zhou
IPC2002-272142: Detection of Mechanical Damage Using the Magnetic Flux Leakage Technique by L. Clapham, Vijay Babbar, Thana Rahimi and David Adriorton
IPC2002-27320: A Satellite-Based Mechanical Damage Management Solution by Greg O’Neil, Michael Besserer, Daron Moore and Louis Fanjleis
IPC2002-000271: Detection of Mechanical Damage Using the Magnetic Flux Leakage Technique by Lynnach Clapham, Vijay Babbar and James Byrne
IPC2002-000326: Integrity Analysis for Dents in Pipelines by Brian N. Leis, Thomas P. Forte and Xiaokui Zhu
IPC2004-000274: Quantifying the Severity of Mechanical Damage by C. R. Torres and A. P. Dean
IPC2006-10043: Understanding Magnetic Flux Leakage Signals From Dents by Lynnach Clapham, Vijay Babbar and Alex Rubenstein
IPC2006-10101: Calculation of Strains in Dents Based on High Resolution Line Caliper Survey by Stanislav A. Lukasiewicz, Jaroslav A. Czyz, Chao Sun and Samer Adeb
IPC2006-10138: Experimental and Numerical Modelling of Pipeline Denting by Site ‘plane Hertz-Cle’-mers
IPC2006-10141: A Time Dependent Model for Assessing the Significance of Mechanical Damage by Michael Martin and Robert (Bob) Andrews
IPC2006-10192: Effect of Pre-Deformation on Fatigue Crack Propagation Life of X60 Pipeline Steel by Xinwei Zhao, Jinheng Luo, Rong Wang, Maoosheng Zheng and Baosheng Dong
IPC2006-10396: Evaluation of the Resistance of X120 Pipe to Mechanical Damage by Antonio Lucci, Gianluca Mannucci, Giuliano Malatesta and Nicholas E. Biery
IPC2006-10407: Management of Pipeline Dents and Mechanical Damage in Gas Pipelines by David J. Warman, Dennis Johnston, John D. Mackenzie, Steve Rapp and Bob Travers

IPC2006-10426: The Role of Technology in Preventing/Detecting Mechanical Damage by Mark Hereth, Keith Lewis and Rick Gailing
IPC2006-10492: Assessing the Use of Composite Materials in Repairing Mechanical Damage in Transmission Pipelines by Chris Alexander and Franz Worl
IPC2006-10513: Deterministic Assessment of Minor Mechanical Damage on Pipelines by M. J. Rosenfeld, Alan Bechert, Bhaskar Neogi, U. J. Baskurt and Eilen Johnson
IPC2006-44278: Modelling Magnetic Flux Leakage Signals From Dents by Lynnach Clapham, Vijay Babbar, Kris Marine, Alex Rubenstein and Murat Zirni
IPC2006-64304: Towards a New Limit State Function for Determining the Failure Pressure of a Pipeline Containing Mechanical Damage by Chua Jandu, Bob Francini, Mike Taylor and Andrew Francis
IPC2006-64345: Reduction Factors for Estimating the Probability of Failure of Mechanical Damage Due to External Interference by Andrew Cosham, Jane Haswell and Neil Jackson
IPC2008-64377: Testing of a Dual Field Magnetic Flux Leakage (MFL) Inspection Tool for Detecting and Characterizing Mechanical Damage Features by Alex Rubenstein, Steffen Papen and Bruce Nelderthor
IPC2010-31242: A Synthesized Approach to Pressure Reduction for Investigating Mechanical Damage by M. J. Rosenfeld
IPC2010-31246: Effect of Geometry, Material and Pressure Variability on Strain and Stress Fields in Dented Pipelines Under Static and Cyclic Pressure Loading Using Probability Analysis by Housin Mohammad Al-Malhotra and Abul Fazal Al-Arif
IPC2010-31409: Investigate Performance of Current In-Line Inspection Technologies for Dents and Dent Associated With Metal Loss Damage Detection by Ming Gas and Rani Krishnamurthy
IPC2010-31417: Mechanical Damage of Pipelines at Low Operating Pressure by Khalid A. Farrag and Robert B. Francis
IPC2010-31470: Design of Pipeline Damage for the BP K100 Operational Trial by Robert M. Andrews, James Johnson and Julie Cropley
IPC2010-31561: Evaluation of Composite Sleeve Repair in Dented and Ovalled Natural Gas Pipeline by Byon G. Souza Filho, Cristiane S. Frota, Fabio M. Mattu, Gabriel Peru and Walter Schultz Neto
IPC2010-31688: Understanding Magnetic Flux Leakage Signals From Gouges by Lynnach Clapham, Vijay Babbar, Jian Dien Chen and Chris Alexander
IPC2010-30017: Integrity Assessment of API 5L X65 and X70 Pipelines With Mechanical Damages by Kyo Jung Yeom, Yong Kweon Lee, Ryu Hwan Oh, Choel Man Kim and Woo Sih Kim
IPC2010-30022: Multiple Data Set ILI for Mechanical Damage Assessment by Chris Goller, James Simk and Jed Ludlow
IPC2012-30137: Development of a Validated Dented Pipe Finite Element Model by Sanjay Tiku, Vlado Semiga, Aaron Dinovitzer and Geoff Vignal
IPC2012-30433: Pipeline Mechanical Damage Integrity Management Framework by Vlado Semiga, Sanjay Tiku and Aaron Dinovitzer
Operationalization of Mechanical Damage Assessment

IPC Papers...

IPC2012-10621: Full Scale Experimental Database of Dent and Gouge Defects to Improve Burst and Fatigue Strength Models of Pipelines. By Mures Zarea, Remi Batisse, Brian Leis, Philippe Cardin and Geoff Vignal
IPC2014-38017: Stress Localization in the Dent of a Linepipe by Jandark Oshana-jaajo, Hossein Ghaednia, Jamshid Zohreh Heydariha and Sreekanta Das
IPC2014-33413: Computational Model Based Method for Defining an Improved Criterion for Dent Fatigue Assessment. By Maxim Leconi, Stéphane Hertz Clemens, Philippe Notariani and Magali Pollo
IPC2014-33445: Mechanical Damage and Fatigue Assessment of Dented Pipelines Using FE. By W. Half and S. Kauy
IPC2014-33451: Application and Advancement of EMAT Il Technology for the Inspection of Cracks in Dents by Jeff Sutherland, Andrew Mann, Udayasankar Arumugam
IPC2014-33516: Characterization of Topside Mechanical Damage by Rick Yuhua Wang, Richard Kania, Udayasankar Arumugam and Ming Gao
IPC2014-33538: Experimental Investigation on Combined Dent and Gouge Defects on Vintage Steel Transmission Pipelines by Mures Zarea, Stéphane Hertz-Clemens, Remi Batisse and Philippe Cardin
IPC2014-33818: Pipeline Mechanical Damage Excavation Process Review and Recommendations by Abdelfattah Friedj, Aaron Dvoritzer, Geoff Vignal and Sanjay Tikoo
IPC2016-64040: Risk-Based Mitigation of Mechanical Damage by Fan Zhang, Guo Dejandri, Jing Ma
IPC2016-64097: MEASURING CRITICAL STRAINS IN DENT DEFECT OF OIL AND GAS PIPES by Hossein Ghaednia, Jamshid Zohreh Heydariha, Jandark Oshana-jaajo, Sreekanta Das
IPC2016-64098: EFFECT OF CRACK DEPTH ON BURST STRENGTH OF X70 LINEPIPE WITH DENT CRACK DEFECT by Hossein Ghaednia, Jamshid Zohreh Heydariha, Richard Kania, Rick Wang, Sreekanta Das
IPC2016-64136: Assessment of In-Line Inspection Performance and Interpretation of Field Measurements for Characterization of Complex Dents by Jordan G. Steenerson, Luis Torres, Matthew J. Fowler
IPC2016-64216: Detection of Crack-related Features Within Dented Pipe Using Electromagnetic Acoustic Transmission (EMAT) Technology by Geoff Vignal, Jeffrey Sutherland, Kastyn Kond, Luis Torres, Stephanie Tappert
IPC2016-64284: New classification approach for dents with metal loss and corrosion along the seam weld by J. Bruce Nestrethor, James Simm, Jeff Ludlow
IPC2016-64470: On the Use of Surrogate Models in Reliability-Based Analysis of Dent Pipes by Doug Langer, Mantasee Kainat, Samer Adeeb, Sheeran Hanif
IPC2016-64490: Evaluating Dents with Metal Loss Using Finite Element Analysis by David Kemp, Joseph Brattton, Justin Gossard, Shane Finneran, Steven J. Polasik
IPC2016-64530: Improved Pipeline Dent Integrity Management by Amir Esraeighi, Luis Torres, Mark Piazza, Sanjay Tikoo, Vaid Semiga
IPC2016-64548: Study of a Plastic Strain Limit Damage Criterion for Pipeline Mechanical Damage Using FE and Full Scale Denting Tests by Ming Gao, Rave Krishnamurthy, Richard Kania, Rick Wang, Udayasankar Arumugam
IPC2016-64680: Finite Element Modeling and Quantification of Mechanical Damage Severity in Pipelines by Brian Leis, Xian-Kui Zhu
IPC2016-64690: On the Use of Surrogate Models in Reliability-Based Analysis of Dented Pipes by Doug Langer, Mantasee Kainat, Samer Adeeb, Sheeran Hanif

PHMSA Research...

DTR556-02-T-0002, Mechanical Damage Inspection Using MFL Technology
DTR556-04-T-0009, Mechanical Damage at Welds
DTR556-04-T-0006, Effectiveness of Prevention Methods for Excavation Damage
DTPHS5-05-T-0001, Understanding Magnetic Flux Leakage (MFL) Signals from Mechanical Damage in Pipelines
DTR57-06-C-10004, In-Line Nondestructive Inspection of Mechanical Defects in Pipelines with Shear Horizontal Wave EMAT
DTPHS6-06-T-000016, Development of Dual Field MFL Inspection Technology to Detect Mechanical Damage
DTPHS6-06-T-000016, Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection
DTPHS6-06-X-000029, Mechanical Properties and Crack Behavior in Line Pipe Steels
DTPHS6-08-B-000011, Structural Significance of Mechanical Damage
DTPHS6-08-B-000023, Validation for Flaw Acceptance of Mechanical Damage to Low Stress Natural Gas Pipelines
DTR57-09-C-10046, Digital Imaging of Pipeline Mechanical Damage and Residual Stress
DTPHS6-10-T-000009, MWM-Array Characterization of Mechanical Damage and Corrosion
DTPHS6-10-T-000013, Dent Fatigue Life Assessment - Development of Tools for Assessing the Severity and Life of Dent Features
DTR556-04-T-0009, Mechanical Damage at Welds
DTR556-04-T-0006, Effectiveness of Prevention Methods for Excavation Damage
DTPHS6-05-T-00001, Understanding Magnetic Flux Leakage (MFL) Signals from Mechanical Damage in Pipelines
DTPHS6-06-T-000016, Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection
DTPHS6-06-X-000029, Mechanical Properties and Crack Behavior in Line Pipe Steels
DTPHS6-08-T-000011, Structural Significance of Mechanical Damage
DTPHS6-10-T-000013, Dent Fatigue Life Assessment - Development of Tools for Assessing the Severity and Life of Dent Features
PHMSA Full Scale Testing of Interactive Features for Improved Models(MD-4-11)
- Comparison of Results from Residual Stress / Strain Measurement Techniques Based on Variations in Magnetic Permeability(MD-10)
- Full Scale Testing of Real Mechanical Damage Features Using Recovered Pipe(MD-1N)
- Selection and Management of Mechanical Damage Test Samples from Field Removal(MD-1L)
- Creation of Dent and Gouge Defects for Inspection Technology Evaluation and Repair - Vintage Steels Without and With Cracks - Extension of MD-4-6 Project or DOT Project(MD-1-10)
- Contributions to the "Allowable Strain Limits for Dents" - Dents with Cracks and Gouges(MD-1-8)
- Assessment of Delayed Failure for Mechanical Damage - Under Constant Pressure(MD-4-8)
- Full Scale Experimental Validation of Mechanical Damage Assessment Models(MD-4-1)
- Improved Model for Predicting the Burst Pressure of Dent + Gouge Damage(MD-4-3)
- ImprovModel for Predicting the Time/Cycle Dependent Behavior of Dent + Gouge Damage(MD-4-4)
- Acoustic Source Level and Signature Measurement of Pipeline Scratches and Gouges(MD-4-5)
- Full-scale Experimental Validation of Mechanical Damage Assessment Models - Extension of MD-4-1 (MD-4-6)
- Full-scale Experimental Validation of Mechanical Damage Assessment Models - Options MD-1 (MD-4-7)
- DOT PROJECT: Ultrasonic Measurements of Strains in Full Acoustic Source Level and Signature Measurement of Improved Model for Predicting the Time/Cycle Dependent Burst Pressure of Dent
- Full Assessment of Delayed Failure for Mechanical Damage - Without and With Cracks
- Technology Evaluation and Repair - Vintage Steels
- Characterization of Features(MD-4-1)
- Validation/Calibration(MD-4-1)
- Guidelines for Safe Inspection and Repair of Mechanical Damage - Steels (MD-4-11)
- Advanced Material Characterization of Dent and Gouge Samples for Improved Strain Evaluation & Implementing Damage Mechanics Modeling(MD-4-12)
- Neutron Diffraction Measurements of Residual Strain Associated with Dents and Gouges in Pipelines(MD-1-9)
- Examining Crack Growth Rates in Dents(MD-4-13)
- Evaluation of Time-based Criteria to Repair Mechanical Damage(MD-4-13)
- Fatigue Screening and Life Assessment of Pipelines, Dents, and Dents Interacting with Welds(MD-4-9)
- Dent Integrity Management and Modeling - Shallow Dents with Limited Corrosion and Shallow Restrained Dents(MD-4-14)
- Full Scale Testing of Interactive Dent Features for Improved Models(MD-4-15)
- Performance Evaluation of ILI Systems for Detecting and Discriminating Metal Loss, Cracks and Gouges in Geometric Anomalies(MD-1-13)
- Assessing Crack Growth Rates in Dents(MD-1Q)
- New Multi-Year Project: Remaining Life Model and Assessment Tool Reg. Dents and Gouges(MD-4-16)

**PRCI Research**

- 66 IPC Papers related to dents and mechanical damage
- 35 PRCI Projects
- 21 PHMSA Projects

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<th>Integrity Assessment</th>
<th>ECA/FFP</th>
<th>Direct Examination</th>
<th>Validation/Calibration</th>
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Operationalization of Mechanical Damage Assessment

A continuum of assessment...

As Assessed...

[Diagram showing a spectrum from ILI Plain Dents to ILI Dents w/ ML with a defect but significant remaining life]

Result

What are the priorities?

1. Safety during excavation (e.g., rock removal)
2. Via in-line inspection, confirm dents with no damage with high reliability
3. Validated non-destructive examination for defect assessment and on-going ILI validation
4. In-line inspection analysis of features within dents and guidelines for response
5. ECA and FFS Guidelines and Acceptance Criteria
6. Repair Criteria
7. Repair Methods
So, the questions are...

- What is the ability to fully utilize research and practice beyond prescriptive guidelines?
- Is there an ability to develop reliability models and to establish acceptance limits?
- Can or should more refined consequence assessment be considered in the decision process?
- Even though certain defects are confirmed, can the remaining useful life be relied upon (it's not binary)?

What are the gaps?

- Transition from construction to operations
- Reliability approach as opposed to current deterministic approach
- Recognition that most operators (and industry) don't have qualified resources to support complex program
- Characterization of features within a deformation (via ILI) with high reliability
- Prescriptive guidelines and regulations can not fully consider all factors
Thank you!
It’s time to hear from you!

Reliability Modeling Schematic..