Pipeline Research Council International, Inc.

PRCI EC-2-9 (2019)
Peer Review of the Plausible Profiles (Psqr) Corrosion Assessment Model

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San Diego
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PRCI 2019 project: EC-2-9 – Peer Review of the Plausible Profiles (Psqr) Corrosion Assessment Model

Objectives

- Peer review and vet the Psqr model developed by TransCanada (TC)
- Share method and benefits – common goals of safety & optimization
- Provide mainstream methodology for industry

Execution plan

- Conduct PRCI workshops with related SMEs, with options of
  - Workshop #1- June 20th 2018 at PRCI TDC in Houston
  - Workshop #2- September 26th 2018 in Calgary (during the IPC tutorial time)
- Obtain peer reviewed report with feedback from official reviewers
  - John Kiefner, Michael Rosenfeld, Ming Gao/Ravi Krishnamurthy, Phil Hopkins, Andrew Cosham and Maher Nessim
## Roles and Responsibilities

<table>
<thead>
<tr>
<th>Time</th>
<th>Role and Responsibilities</th>
</tr>
</thead>
</table>
| **Before workshops**  | ▪ Reviewers will be contacted by John Kiefner  
                          ▪ Reviewers and PRCI member participants will be provided with a pre-read               |
| **At the workshops**  | ▪ TC presents model to invited expert reviewers and PRCI members  
                          ▪ TC discusses safety aspects, cost benefit, applicability etc.  
                          ▪ Reviewers & PRCI members participate in workshop  
                          ▪ All – discuss, provide constructive feedback                                      |
| **After workshops**   | ▪ Reviewers review technical report  
                          ▪ Reviewers’ comments and feedback provided to John Kiefner(JK)  
                          ▪ JK collates all comments and discusses with TCPL and reviewers  
                          ▪ JK provides final report to PRCI                                             |
Current Status

- Two workshops completed
- TransCanada’s technical report under review
- Software sharing in progress
- Preliminary PRCI report including collated comments by John Kiefner completed by end of 2018
Background
Corrosion - major integrity threat - ~70% of digs, ~80% of ILIs

Key integrity decisions that use Assessment models
- ILI anomalies to excavate?
- Excavated anomalies to repair?
- Derate required?

Decisions are most sensitive to
- Model error
- ILI measurement error
- Growth rates
### What is a Desirable Model?

More precise and accurate models safely reduce digs.

<table>
<thead>
<tr>
<th>Pipeline section</th>
<th>Total number of Clusters</th>
<th>Excavation decision – number of features with FPR ≤ 1.25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>B31G</td>
</tr>
<tr>
<td>1</td>
<td>23502</td>
<td>868</td>
</tr>
<tr>
<td>2</td>
<td>650</td>
<td>130</td>
</tr>
<tr>
<td>3</td>
<td>169</td>
<td>16</td>
</tr>
</tbody>
</table>

Choice of model has high impact on the number of digs.
Learnings

- Learnings from operations
  - Large morphologies-caused failures but models developed on simple clusters
  - Many excavations/derates with wide corrosion

- Learnings from RSTRENG Development Project
  - River bottom profile - the worst case but not probable for wide corrosion
  - Circumferential separation and strengthening due to higher WT
Objective

RSTRENG is conservative for wide corrosion - gives large number of excavations

Objective:

- Improve the RSTRENG model for assessing large corrosion morphologies
  - reduce conservatism while improving safety
  - quantify model error
The Journey

Burst tests on 14 corrosion clusters (2015)

Identified areas of conservatism in RSTRENG

Developed Psqr model and software

Performed Pilot studies to see impact

Sensitivity studies and validation

Internal and external Technical review

Communicate – PRCI, CEPA, IPC (Patent pending)

Further Industry review and sharing (PRCI project)

Performed 16 more tests and refined (2018)
Psqr Overview
Overview of ASME B31G Models

\[ P_b = \frac{2t}{D} \times F(YS) \times \frac{1-SF \times \left(\frac{d_{\text{max}}}{t}\right)}{1-SF \times \left(\frac{d_{\text{max}}}{t}\right)/M} \]

\[ M_1 = \sqrt{1 + \frac{0.81^2}{\frac{L^2}{Dt}}} \]

\[ M_2 = \begin{cases} \sqrt{1 + 0.6275 \frac{L^2}{\frac{Dt}{L}^2} - 0.003375 \frac{L^4}{(\frac{Dt}{L})^2}} & \frac{L^2}{L \frac{Dt}{L}^2} \leq 50 \\ 3.3 + 0.032 \frac{L^2}{\frac{Dt}{L}^2} & \frac{L^2}{L \frac{Dt}{L}^2} > 50 \end{cases} \]

<table>
<thead>
<tr>
<th>Method</th>
<th>Shape idealization</th>
<th>Shape Factor (SF)</th>
<th>Flow Stress F(YS)</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>B31G</td>
<td><img src="image" alt="ASME B31G" /></td>
<td>2/3</td>
<td>1.1 * YS</td>
<td>Two-term, ( M_1 )</td>
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<tr>
<td>Mod. B31G 0.85dL method</td>
<td><img src="image" alt="Modified ASME B31G" /></td>
<td>0.85</td>
<td>YS + 10 ksi</td>
<td>Three-term, ( M_2 )</td>
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<tr>
<td>Mod. B31G eff. area method (RSTRENG)</td>
<td><img src="image" alt="RSTRENG" /></td>
<td>( \frac{d_{\text{eff}}}{d_{\text{max _ Aeff}}} )</td>
<td>YS + 10 ksi</td>
<td>Three-term, ( M_2 )</td>
</tr>
</tbody>
</table>
Conservatism in Corrosion Idealization

River bottom profile
(most aggressive but not plausible for wide corrosion morphologies)
### Input Required by the Model - 3D Mapping

<table>
<thead>
<tr>
<th>Longitudinal Direction (Length)</th>
<th>Circumferential Direction (Width)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 9 8 8 10 8 7 7 4 0 0 6 11 16 12 12 5 9 5 2 0 0 0 0 0</td>
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<tr>
<td>16 10 8 8 9 11 11 10 9 6 7 4 15 19 23 20 22 17 15 12 8 5 6 2 0 0 0 0 0</td>
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<tr>
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<td>0 0 0 0 0 0 0 0 0 4 9 12 14 18 20 23 21 22 20 20 16 14 12 11 8 3</td>
</tr>
</tbody>
</table>
Plausible Profiles & Pressure Calculation

Longitudinal Direction (Length)

Circumferential Direction (Width)

Profile 1

Profile 2

Profile 3

Profile i

Profile n

PDF

$P_b$
Psqr Results

![Graphs showing Psqr Results](image)

Legend:
- **Green**: RSTRENG
- **Orange**: Predicted burst pressure distribution
- **Purple**: Psqr
- **Red**: Actual test burst pressure
Pressure Calculation Using Psqr Model

3D measurement Input
(depth, length and width)

Effective Area Calculation

Plausible Profiles

Probabilistic Distribution of Pressure
Evolution Map of Model Development

- **NG-18 Equation (toughness-independent)**
  - \(1.1 \times \text{YS} + 10 \text{ ksi}\)

- **B31G**
  - 0.67\(dL\) Method
    - \(\text{SF} = 0.67\)
    - Parabolic Profile
    - B31G

- **Mod. B31G-0.85\(dL\) Method**
  - \(\text{SF} = 0.85\)
  - Arbitrary Profile
  - Mod. B31G-0.85\(dL\) Method

- **Effective Area Method**
  - \(\text{SF} = f(\text{effective area})\)
  - River Bottom Profile
  - Mod. B31G-Effective Area Method
  - RSTRENG

- **Plausible Profiles (Psqr)**
  - Psqr

**Flow stress**

**Bulging Factor**

**Shape Factor**
Compared to RSTRENG, Psqr is **less conservative** and **more precise**
Model Uncertainty

- **Model error: test-to-prediction ratio**
  - actual pipe properties
  - laser scan: lab controlled minimized error

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test-to-prediction ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Psqr method</td>
</tr>
<tr>
<td>Mean</td>
<td>1.13</td>
</tr>
<tr>
<td>Std</td>
<td>0.07</td>
</tr>
<tr>
<td>COV (%)</td>
<td>5.9</td>
</tr>
</tbody>
</table>

- **Psqr vs RSTRENG**
  - Psqr has higher accuracy and precision compared to RSTRENG
  - 14% reduction in model bias
  - 30% reduction in standard deviation
Benefit and Safety
## Case Studies

- **Case I:** 154 immediate features with FPR ≤ 1.25
  
<table>
<thead>
<tr>
<th>Model</th>
<th>Number of features with FPR ≤ 1.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSTRENG</td>
<td>154</td>
</tr>
<tr>
<td>Psqr</td>
<td>31</td>
</tr>
</tbody>
</table>

  80% reduction in feature excavations required

- **Case II:** 170 excavated features
  
<table>
<thead>
<tr>
<th>Model</th>
<th>Number of features with FPR ≤ 1.25</th>
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</thead>
<tbody>
<tr>
<td>RSTRENG</td>
<td>44</td>
</tr>
<tr>
<td>Psqr</td>
<td>5</td>
</tr>
</tbody>
</table>

  89% reduction in feature repairs required
## Expanded Case Studies

### ILI by different ILI vendors

<table>
<thead>
<tr>
<th>Cluster Dataset</th>
<th>Total Number of Features</th>
<th>Excavation decision – Number of Features with FPR ≤ 1.25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>B31G</td>
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<td>ILI Data</td>
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<td>130</td>
</tr>
<tr>
<td></td>
<td>169</td>
<td>16</td>
</tr>
</tbody>
</table>

### Field-measurements on different pipe sections

<table>
<thead>
<tr>
<th>Cluster Dataset</th>
<th>Total Number of Features</th>
<th>Repair decision - Number of Features with FPR ≤ 1.25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>B31G</td>
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<tr>
<td>Laser Scan data</td>
<td>84</td>
<td>81</td>
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<tr>
<td></td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
Results and Impact to Operators

Psqr improves corrosion decisions by reducing unnecessary actions with safety

- Major PI threat - Corrosion
- Decisions that drive actions
- Model highly sensitive to Shape
- Improve Shape representation
- Plausible profiles
- More Precise and Accurate model
- much less digs/repairs
- High Value creation

Threats:
- Corrosion

High Value creation

Model decisions most sensitive to Model
Applicability and Regulations
Applicability

- API 5L X Grade Pipes
- Any corrosion clusters, greater benefit for wider corrosion
- The limits of RSTRENG are also applicable (e.g. maximum depth, brittle failure)

Notes:

- ILI reporting capability developed with ROSEN, Baker Hughes, and GE (BHGE)
Regulations

- To select the corrosion assessment method CFR 192 & 195 and CSA Z662 refer to:
  - ASME B31G standard or methods
  - PRCI PR3-805 report
- ASME B31G-2012 allows:
  - use of a level 3 analysis based on user-defined methodology
- PRCI PR3-805
  - acknowledges the limitation of RSTRENG method and discussed the idea of using multiple profiles
Regulations

- **Section 1.6 of ASME B31G-2012:**
  - “A Level 3 evaluation is a detailed analysis of a specific flaw in accordance with a user-defined methodology, with full justification for loadings, boundary conditions, material properties, and failure criteria. It is intended that a Level 3 evaluation be conducted by a technical specialist having appropriate expertise in the subject of fitness-for-service assessment.”

- **Section 1.8 of ASME B31G-2012, also allows the use of other evaluation methods.**
  - “Other evaluation methods may evolve or come into use which were not contemplated by this document. It is not the intention of this document to prohibit their use, but the user of such methods shall be able to demonstrate that the objective of a safe and reliable assessment of metal loss can be achieved.”
PRCI PR3-805 acknowledges the limitation of RSTRENG method and discussed the idea of using multiple profiles. Here is the excerpt from PRCI PR3-805 regarding multiple profiles:

“A final point that must be made with regard to any type of profile representation of metal loss is that some excess conservatism will always be present when the deepest parts of the corrosion are not lined up along the axis of the pipe and when deeper portions of the pitting are separated by islands of greater remaining wall thickness. Within the present state of technology, it is not practical to deal analytically with these variables.”
Contact Information

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- Jason Yan
  jason_z_yan@transcanada.com

TransCanada Pipelines Ltd

Thank You and Questions
Reference

Reference