The Use of XHab™ for Reinforcement of Axially Aligned Notches in Pipelines

David Miles, Pipestream Inc.
2nd Annual CRUG Meeting
September 7, 2012
Brief Introduction to XHab

- Pipeline repair and reinforcement method for longer pipeline sections
  - Not directly competing with hand-applied repair systems
  - Providing an alternative to pipeline replacement
- Increases the operating pressure of a corroded or damaged pipeline back to its original MAOP.
- Modifies the hoop stress related to class location change (currently with special permit).
- Based on steel wrap, provides good response at low strain cycle levels which can be important in fatigue situations.
Brief Introduction to XHab

Prototype machine (XHab1) provided good experience...
Brief Introduction to XHab

...commercial machine (XHab2) much smaller and lighter!
XHab for Axial Cracks

- Other testing (dents, external defects, plain pressure cycling) has shown good response from the XHab reinforcement, even at very low strain levels.
- Axial cracks (e.g. fatigue cracks or from Stress Corrosion Cracking) may propagate under operational stress cycle ranges at low strains.
- XHab reduces both the average stress and stress cycle range and could substantially reduce crack growth rate, or potentially even bring below threshold level.
XHab for Axial Cracks

- Testing program on axially-notched pipes just completed with Stress Engineering Services
- This is the first phase in a program to demonstrate ability to repair crack-like defects without grinding

- Other repair wrap and sleeve products have been tested in the past for repair of cracks, but only aimed at spot repairs rather than extended lengths
Notch Geometry

- EDM (electrical discharge machining) for control and repeatability of notch defects across a number of samples
- Preliminary assessments by Stress Engineering were simple estimates
  - Performed before pipe material data collected
  - Mostly based on nominal dimensions and properties
  - Quite conservative in their approach
  - Performed to size defects to ensure noticeable difference in results against experimental “scatter” but within reasonable timeframe
  - Not necessarily expected to be accurate predictions of actual tests
# Notch Geometry

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Burst Tests</th>
<th>Fatigue Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>6 in.</td>
<td>6 in.</td>
</tr>
<tr>
<td>Width</td>
<td>0.02 in.</td>
<td>0.02 in.</td>
</tr>
<tr>
<td>Depth</td>
<td>0.094 in. (0.5 t)</td>
<td>0.062 in (0.33 t)</td>
</tr>
<tr>
<td>Location (ERW seam at 12 o’clock)</td>
<td>6 o’clock</td>
<td>3 o’clock 9 o’clock</td>
</tr>
</tbody>
</table>
Wrap Design

• Thickness of wrap was based around reinforcement required for re-rating nominally defect-free pipe
• Testing performed on 12.75” x 0.188” X52 pipe (AYS=60000psi, ATS=70000psi)
• Design wrap thickness to reduce hoop stress from, say, 72% SMYS to <50% SMYS
• Total strip thickness of 0.10” applied to pipe in 3 layers
• Strip applied to pipe at zero pressure
• Theoretical reduction in hoop stress:
  • Hoop stress in wrapped section = 65% of hoop stress in unwrapped section
Burst Test Arrangement

- Burst test specimens in pit with lid
- Maximum pressurization rate of 10psi per second
- 5 minute holds:
  - 766psi (50% SMYS)
  - 1104psi (72% SMYS)
  - 1240psi (estimated unrepaired failure)
  - 1533psi (100% SMYS)
- Increase pressure to failure
Burst Test Results

- Unrepaired pipes fractured at the notch location
- Simplified initial estimate 1240psi

\[
\begin{align*}
P_{b_1} &= 1457 \text{psi} \\
P_{b_2} &= 1473 \text{psi} \\
P_{b_3} &= 1467 \text{psi} \\
P_{b_{\text{av}}} &= 1466 \text{psi} \\
\text{CoV} &= 0.6\%
\end{align*}
\]
Burst Test Results

Pressure vs Strain (Hoop)
Unrepaired Notched Burst Sample #1

Burst @ 1,457 psi

Pressure (psi)

Hoop Strain (microstrain, µε)
(10,000 microstrain equals 1 percent strain)

Hoop 1
Hoop 2
Hoop 3

Innovative Pipeline Technology,
Value Focused Solutions
Burst Test Results

- Repaired pipes fractured in base pipe away from repair
- Simplified initial estimate 2064psi (Barlow formula using AYS)

\[
\begin{align*}
P_{b,4} &= 2101\text{psi} \\
P_{b,5} &= 2101\text{psi} \\
P_{b,6} &= 2059\text{psi} \\
P_{b,\text{av}} &= 2087\text{psi} \\
\text{CoV} &= 1.1\%
\end{align*}
\]
Burst Test Results

Pressure vs Strain (Hoop)
Repaired Notched Burst Sample #4

Burst @ 2,101 psi

Pressure (psi)
0 500 1,000 1,500 2,000 2,500

Hoop Strain (microstrain, µε)
(10,000 microstrain equals 1 percent strain)
0 5,000 10,000 15,000 20,000 25,000

Hoop 1
Hoop 2
Hoop 3
Hoop Center on Repair
Hoop 5 Under Repair
Hoop 6 Under Repair

Innovative Pipeline Technology,
Value Focused Solutions
Fatigue Test Arrangement

- Fatigue test specimens in shield structure
- Pipes connected in parallel for pressurization from single pump
- Cycle between 100psi (6.5% SMYS) and 1204psi (78.5% SMYS)
- $\Delta P = 1104$psi (72% SMYS)
- 1 cycle every 7 seconds (approx.)
- Record 5 cycles of data at various intervals during test
Fatigue Test Results

- Unrepaired pipes fatigue / fracture at the notch location
  - Simplified initial estimate 2670 cycles

\[ N_{cf\_7} = 4,085 \text{ cycles} \]
\[ N_{cf\_8} = 4,097 \text{ cycles} \]
\[ N_{cf\_9} = 4,117 \text{ cycles} \]
\[ N_{f\_av} = 4,100 \text{ cycles} \]
\[ \text{CoV} = 0.4\% \]
Fatigue Test Results

- Repaired pipes reached run-out or failure of base pipe remote from repair
- Simplified initial estimate 15650 cycles

\[ N_{c_{10}} = 60,649 \text{ cycles} \]
\[ (2^{nd} \text{ end cap failure}) \]
\[ N_{c_{11}} = 41,409 \text{ cycles} \]
\[ (2^{nd} \text{ end cap failure}) \]
\[ N_{c_{12}} = 60,671 \text{ cycles} \]
\[ (\text{ERW pin hole leak outside repair}) \]
Fatigue Test Results

This particular XHab repair design reduced strain range in pipe by factor of ~2

~0.53 με/psi ~1.05 με/psi

Pressure vs Strain (Hoop)
Pressure cycle on repaired Notch Sample 10
5 cycles recorded @ 20,769 cycles

Sample 10 Hoop 1
Sample 10 Hoop 2
Sample 10 Hoop 3
Sample 10 Hoop 4 R
Sample 10 Hoop 5 UR
Sample 10 Hoop 6 UR

On pipe outside wrap
On pipe under wrap
On top of wrap above notch

(10,000 microstrain equals 1 percent strain)
Fatigue Test Results

- A reduction in stress range reduces initial stress intensity factor range ($\Delta K$) by the same amount.
- Large effect on rate of crack growth rate ($da/dN$):
  - Factor of 2 on $\Delta K$
  - $\rightarrow$ Factor of 8 on $da/dN$
- Reducing $\Delta K_{\text{initial}}$ (by reducing stress range) has two beneficial effects:
  - Reduced $da/dN$ initially
  - Slower increase in $\Delta K$ since $a$ increases much more slowly.

Figure from “Fatigue crack growth rates in six pipeline steels” by A Bussiba et al., IPC2006-10320.
Fatigue Test Results

- SES considered what these results might mean for a real gas transmission pipeline
  - ‘Aggressive’ operating history gives 58 equivalent full MAOP (72%) cycles per year
  - Include a factor of 10 on the fatigue design life (typical value)
    - Unreinforced pipe: 6.9 years
    - Reinforced pipe: 103.4 years
  - Values reduced (but maintaining x15 factor between them) for liquid pipelines, where pressure cycle tends to be more aggressive
Next Steps

1. Re-analyze results based on measure pipe fracture toughness properties
   • Identify differences between initial (simplified) predictions and actual results
   • Any other effects e.g. restricting crack mouth opening due to adhesive?

2. Additional testing on notched + pre-cracked pipe specimens
   • To account for differences between flat-bottom notch and sharp crack at the time of repair

3. Test effectiveness of repair on pipe with cracks (SCC) removed from service
   • Seeking support from operator(s) to identify and supply appropriate pipe

4. Refine design criterion for repair thickness / application pressure
   • Use of finite element analysis to cover sensitivities
Closing Thoughts

• Bonded wrap repairs or sleeves have been considered for non-ground crack repairs previously, but not over extended length
• Technologies move forward:
  • Materials
  • Assessment tools and methods
• We shouldn’t discount the potential for alternative methods simply because “something similar” was not taken up previously
  • “Similar” can prove very different in key areas
• As engineers, we should always be exploring the boundaries of our knowledge (safely, of course...)