ASSESSING THE USE OF COMPOSITE MATERIALS IN REPAIRING AND REINFORCING OFFSHORE RISER PIPES

Presented to the Regional Operations Technology Assessment Committee (ROTAC) Meeting
Minerals Management Service (Pacific OCS Region)
OTRC Presentation

Chris Alexander, Staff Consultant/Senior Associate
Stress Engineering Services, Inc.
chris.alexander@stress.com · (281) 897-6504 (direct)
Presentation Outline

• Review of current composite repair state of the art
• Joint Industry Project (JIP) Program
  – Task overview and schedule
  – Manufacturer participation
  – Analysis phase
  – Testing phase
  – Guideline development
• Closing comments
Uses of Composite Materials
(repair and structural reinforcement)

- Metal wall loss (due to corrosion)
- Plain dents
- Mechanical damage (dents with a gouge)
- Re-rating pipeline system to achieve higher operating pressures
- Corrosion repair and replacement
  - Under insulation coating (UIC)
  - Wear-resistant coatings (e.g. saddles)
  - Underwater coatings
Types of Composite Repairs (used to repair pipeline systems)

• **Wet lay-up systems** (e.g. Armor Plate Pipe Wrap, Diamond Wrap, Aquawrap, Comptek)
  – Monolithic
  – Can be applied to non-straight geometries
  – Versatility in range of epoxy products (e.g. underwater, high temperature, etc.)

• **Layered systems** (e.g. Clock Spring and PermaWrap)
  – First widely-used composite repair system
  – Layered repair system
  – Limited to repair of straight pipes
Government Regulations
(from the U.S. Department of Transportation)

On January 13, 2000, **Pipeline Safety: Gas and Hazardous Liquid Pipeline Repair**, was issued by the RSPA of the Department of Transportation, went into effect.

According to this document, the requirement for repairing corroded and dents in pipelines is as follows,

...repaired by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe.
Guidelines for Evaluation of Composite Repair Methods

The *basic fundamental issues* for evaluating composite repair methods are as follows:

- Strength of the composite material
- Environmental effects (e.g. cathodic disbondment, temperature, acids and alkalines)
- Effects of pressure (both static and cyclic)
- Mechanics of load transfer from pipe to wrap
- Long-term performance issues
- Consistency in application and quality control in manufacturing
Mechanics of Composite Repair Methods

Equation defining burst pressure

\[ P_{burst} = \frac{\sigma_{ult_{pipe}} \cdot t_{pipe} + \sigma_{ult_{wrap}} \cdot t_{wrap}}{r_{inside}} \]

\( P \) = Internal pressure
\( \sigma \) = Material failure stress
\( t \) = Thickness of material
\( r \) = Radius of pipe

Note:
The above calculation is based on thin-wall shell theory and is not applicable for thick-walled pipes with diameter to wall thickness ratios less than 20.
Pipe-to-Composite Load Transfer
(Hoop Strain During Pressurization)

Hoop Strain as a Function of Internal Pressure

Comptek epoxy resin composite repair system (Sample #2)
12.75-in x 0.219-in, Grade X52 pipe with 60 percent corrosion
Burst pressure of 2,931 psi (in unrepaired section of test sample)
Observations on Current Composite Repair Methods

- For more than 10 years, the pipeline industry has been making repairs using composite materials
- A significant body of research exists addressing a variety of repair types
- The missing link in most of the composite repair systems is long-term test data (especially in terms of the adhesive systems)
JIP Program

• Elements of the program
  – Task overview and schedule
  – Manufacturer participation
  – Analysis phase
  – Testing phase
  – Guideline development
# Task Overview and Schedule

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Year 2006</th>
<th>Year 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task 1</strong> - Information gathering stage (review current state of the art)</td>
<td>May</td>
<td>June</td>
</tr>
<tr>
<td><strong>Task 2</strong> - Determining typical riser loads</td>
<td>November</td>
<td>December</td>
</tr>
<tr>
<td><strong>Task 3</strong> - Document range of existing limitations</td>
<td>October</td>
<td>November</td>
</tr>
<tr>
<td><strong>Task 4</strong> - Identify optimization opportunities and FEA of repair systems</td>
<td>September</td>
<td>December</td>
</tr>
<tr>
<td><strong>Task 5</strong> - Testing phase and evaluation of current systems</td>
<td>January</td>
<td>February</td>
</tr>
<tr>
<td><strong>Task 6</strong> - Complete documentation and preparation of final report</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Completed task**
- **Incomplete task OR task in-progress**

- **Task 1** - Information gathering stage
- **Task 2** - Anticipated loads
- **Task 3** - Document range of limitations of existing technology
- **Task 4** - Identify opportunities and concepts for emerging technologies (includes analysis efforts based on finite elements)
- **Task 5** – Full-scale testing
- **Task 6** - Final report and documentation
Analysis Phase

• Simulation of repair considering loads acquired during Task 2
• Finite element analysis employing specific composite properties and elastic-plastic material properties for steel riser pipes
• Limit analysis methods will be used to capture the lower bound plastic collapse load and corresponding design load
Testing Phase

- Full-scale testing using loads acquired during Task 2 (8-inch NPS pipe)
- Three test samples integrate 50% corrosion
  - 8-ft long Internal pressure sample (see NOTE)
  - 8-ft long Pressure and tension
  - 15-ft long Pressure, tension, and bending
- Strain gages installed in corroded areas beneath repairs
- In testing limit analysis methods used to capture the lower bound plastic collapse load

**NOTE:** Test variables shown in BOLD RED is the one incrementally increased to capture the lower bound collapse load
Testing Details
(Sample loading and defect configuration)

(Tensile Force (both ends))

(Four-point bending force locations)

110 inches

55 inches

180 inches (15 feet)

δ₁  δ₂  δ₃  δ₄  δ₅

Selected displacement measurement locations

Break corners

24-inches

30° taper

0.200 inches deep

Presentation to the MMS ROTAC Meeting
Camarillo, California · September 19, 2006
Testing Details
(Strain gage details – 12 per sample)

- Gages @ A and B will be beneath composite repair

Bi-axial strain gage location
(install gages at 0°, 90°, and 180°)

Center of groove

180-inches
78-inches
24-inches
(corroded region)

42-in

6-in

Gages @ A and B will be beneath composite repair
Preliminary Test Results
(Burst pressure sample)

Hoop Strain versus Applied Internal Pressure
Strain gage readings on pipe beneath repair

- Unrepaired Sample
- Product C
- New Pipe (no corrosion)
- Product D

Internal Pressure (psi)
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Microstrain (10,000 ms = 1 percent strain)
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000 19000 20000

Presentation to the MMS ROTAC Meeting
Camarillo, California · September 19, 2006
Preliminary Test Results
(Tension loading sample)

Axial Strain versus Applied Tension Load
Strain gage readings on pipe beneath repair

Microstrain (10,000 ms = 1 percent strain)

- Unrepaired Sample
- New Pipe (no corrosion)
- Product D
Preliminary Test Results
(Bending load sample)

Bending Strain versus Applied Bending Load
Strain gage readings on pipe beneath repair

- Unrepaired Sample
- Product C
- New pipe (no corrosion)
- Product D

Microstrain (10,000 ms = 1 percent strain)
Repair System Development

- Integrating riser loads
- Expected results for the different load requirements
  - Internal pressure
  - Axial tension
  - Bending
- Essential elements relative to design repair requirements
- Consider riser loads subject to API RP 1111 design stress limits
- Addressing and qualifying potential upset conditions
Path Forward Activities

Under MMS-OTRC Sponsorhip Composite Repair Methods for Steel Pipes (PR# 558-39300 - Dr. Ozden O. Ochoa) the following research tasks are underway

• Implement computational FEA models to validate tests
• Identify & demonstrate “structurally optimized” composite repair concept
• Develop guidelines for MMS with regards to using composite materials to repair offshore risers