History of Composite Repairs in the Pipeline Industry

2015 5th Annual Composite Repair Users Group Workshop

Meeting Date: September 25, 2015
Presented by: Dr. Chris Alexander, P.E.

Taking on your toughest technical challenges.

STRESS ENGINEERING SERVICES INC.
an employee-owned company

Presentation Overview

- Words of tribute for Fred D. Wilson
- Composite repair overview (State of the Art)
- Composite repair timeline
- Industry interest as reflected in PRCI studies
- Case study: Dent reinforcement design
- Looking forward

Fred D. Wilson (1935 – 2015)

Frederick Dean Wilson

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State of the Art

- Composite systems have been used to repair high pressure pipelines for more than 25 years
- The key to integrating composite technology is properly designing and installing systems possessing adequate service life
- Performance testing has been an essential element in demonstrating the capacity of composite repair technology
- Continued “pushing of the envelope”

Composite Repair Timeline (1/3)

(Based on work done by Stress Engineering)

1994 Started testing Clock Spring with GRI

(primary interest reinforcing mechanical damage)

1997 Started testing Armor Plate® Pipe Wrap

(wide range of studies including load transfer, dents, cyclic, etc.)

2000 Started testing for NRI and WrapMaster

2004 Started working with Pipe Wrap

2005 Started testing Aquawrap

2006 Stress Engineering ASME PCC-2 involvement

Start of significant individual operator funding

(e.g. El Paso, TransCanada, Panhandle, Williams, CenterPoint, & Chevron)

Composite Repair Timeline (2/3)

(Based on work done by Stress Engineering)

2008 PRCI long-term buried project (13 mfgs) See below

Armor Plate, Inc. (10 years)
Air Logistics Corporation (3 years)
Clock Spring Company, LLC (3 years)
Citadel Technologies (10 years)
EMS Group (10 years)
Pipe Wrap, LLC (3 years)
T.D. Williamson, Inc. (10 years)
Walker Technical Resources Ltd. (3 years)
Wrap Master (3 years)
3X Engineering (3 years)
Furmanite (3 years)
Neptune (3 years)
Pipestream (10 years)

2009 First meeting of what would become CRUG

Started testing for Western Specialties

2010 Started testing for Pipestream (re-rate / cracks)

2012 Started testing for Fyfe Company

2013 Development of PRCI Comp. Guideline Doc.

Composite Repair Timeline (3/3)

(Based on work done by Stress Engineering)

2014 Elevated temperature testing

Reinforcement of fittings with combined loads

Optimizing composite repair designs using FEA

Validation testing for ASME PCC-2

Dent Validation Collaborative Industry Program

(DV-CIP participants: ROSEN, 5 operators, and 6 repair companies)

2015 Six (6) Joint Industry Programs (JIPs, next slide)

BSEE / PHMSA study sponsorship

2015-2016 JIPs

- Studies being conducted
  - Offshore Study (10,000-hr test in simulated seawater)
  - Onshore Study
  - Load Transfer Study
  - Wrinklebend Study
  - Crack Reinforcement Study
  - Crack Arrestor Study
- Participatign composite manufacturers
  - Air Logistics
  - Citadel
  - Furmanite
  - Milliken
  - NRI
  - Western Specialties

PRCI Research Programs

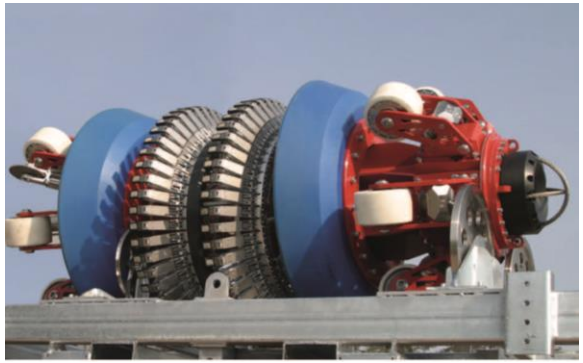
- MATR-3-4 Long-term performance (10-year study)
- MATR-3-5 Repair of dents
- MATR-3-6 Repair of subsea pipelines/risers
- MATR-3-7 Girth weld reinforcement
- MATV-1-2 Wrinkle bend reinforcement
- MATR-3-9 Re-rating to establish MAOP
- NDE 2-3 NDE & Inspection Techniques
- MATR-3-10 Composite Repair Guideline Document
- MATR-3-11 Load transfer / pressure during installation
- MATR-3-12 Effects of delamination on performance
- Composite Roadmap (being updated)

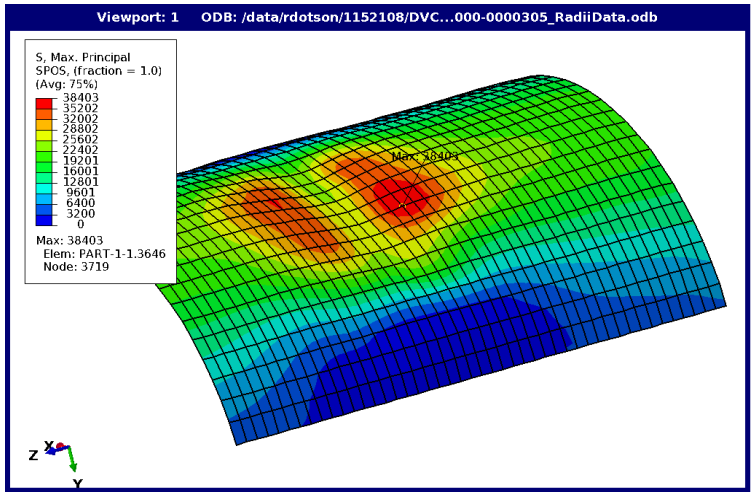
Case Study

Development of design basis for reinforcing dents

Modern Dent Assessment

- ILI geometry tool produces R-θ-Z data
- The geometry data used as input into the finite element (FEA) model
- The FEA model used to calculate dent SCFs
- Literally hundred of dents can be in one pass





Design Basis

- Formulation must take into account stiffness of the composite, relative to the pipe
- Relative stiffness of the pipe (D/t) is an important consideration when evaluating dents
- The starting point is to look for trends in body of existing research, especially strains and composite thicknesses
- If appropriate, consider variations in performance of different fibers

Proposed Design Equation

$$t_{comp} = \frac{1}{M}\left(\frac{E_{pipe}}{E_{comp}}\right)\left(\frac{\Delta P\ D}{2\ f\ S_{yield}}\right)$$

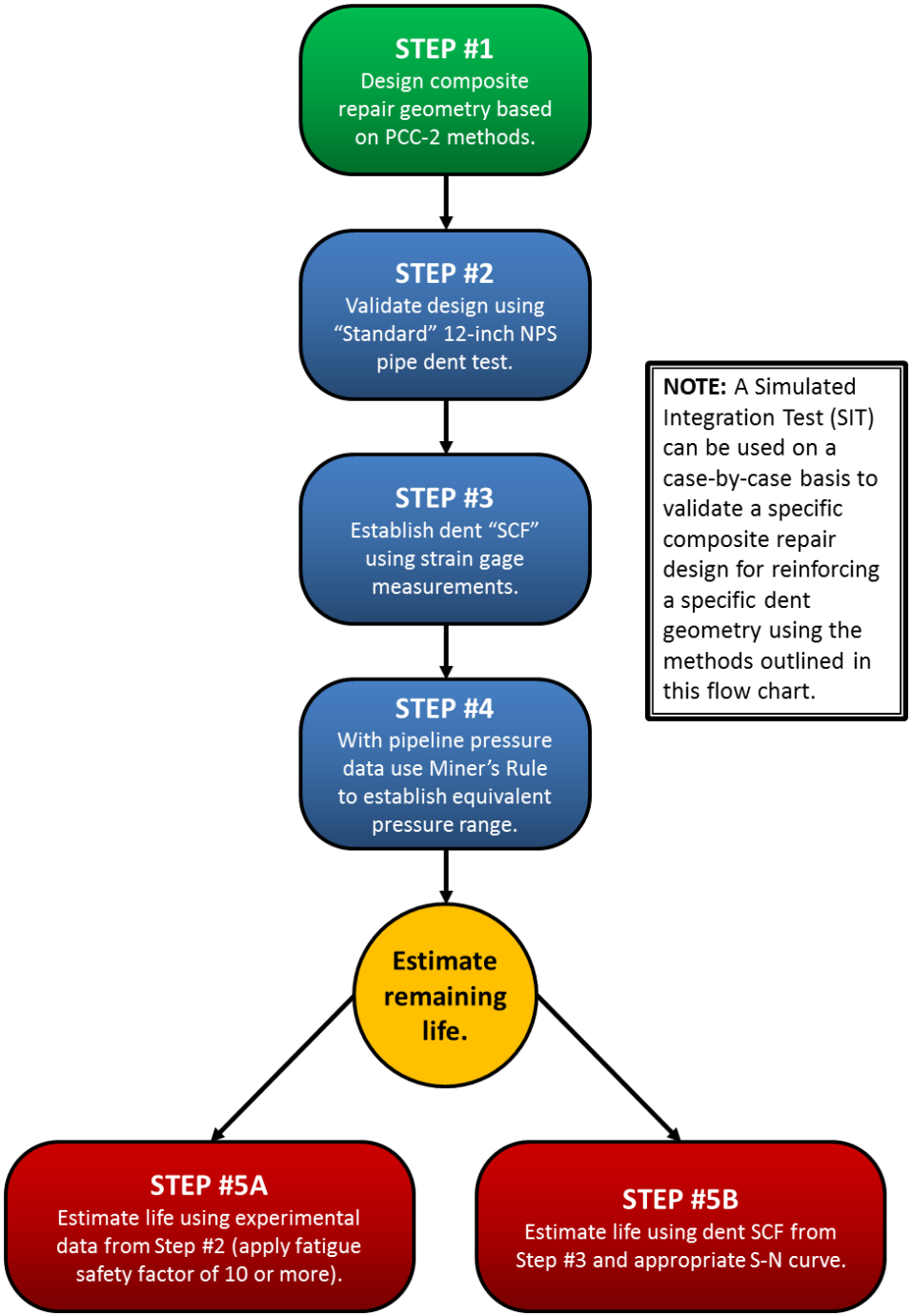
E-glass systems	M = 3.5
Carbon systems	M = 2.0

t_{comp}	Thickness of composite (inch)
M	Empirically-based parameter
E_{pipe}	Elastic modulus of pipe (psi) r
E_{comp}	Elastic modulus of composite (psi)
ΔP	Applied pressure range (psi)
f	Pipeline design factor (0.72 rec.)
S_{yield}	SMYS of pipe (psi)

Goal Seeking Value(s) for "M"

							M factor:	3.5		2		
Sample Number	Material	E_{comp}	N (cycles)	Nominal Pipe Strain (με)	Dent Strain (με)	SCF	t_{repair} (inches)	t_{repair_CALC} (inches)	% diff	t_{repair_CALC} (inches)	% diff	Notes and Comments
DV-CIP Data (24-inch x 0.25-inch, Grade X42 pipe | cycled from 100 to 630 psi, ΔP = 60% SMYS | Average residual dent depth of 4.8% | 100,000 cycle rnuout)												
Unrepaired	N/A	N/A	23,512	835	3,510	4.20	N/A	N/A	N/A	N/A	N/A	Unrepaired: No repair installed
A-PD-24-1	E-glass / urethane	2.28	100,623	836	1,235	1.48	0.928	**0.940**	**-1.3%**	1.645	-43.6%	*Good performance (E-glass)*
AE-PD-24-1	Steel Sleeve	N/A	40,877	831	870	1.05	0.283	N/A	N/A	N/A	N/A	N/A
AE-PD-24-2	Steel Sleeve	N/A	101,999	819	3,720	4.54	0.276	N/A	N/A	N/A	N/A	N/A; No filler material installed
B-SW-24-1	Carbon / epoxy	11.9	102,950	834	1,144	1.37	0.494	0.180	174.3%	0.315	56.8%	Seam weld interaction
B-DC-24-1	Carbon / epoxy	11.9	100,623	830	1,812	2.18	0.484	0.180	168.8%	0.315	53.6%	Corrosion interaction (40% deep)
B-PD-24-1	Carbon / epoxy	11.9	102,950	848	1,198	1.41	0.497	0.180	176.0%	0.315	57.7%	
C-PD-24-1	E-glass / epoxy	4.4	106,252	813	1,178	1.45	0.477	**0.487**	**-2.1%**	0.852	-44.0%	*Good performance / optimized*
C-SW-24-1	E-glass / epoxy	4.4	106,252	813	1,152	1.42	0.503	**0.487**	**3.3%**	0.852	-41.0%	Seam weld interaction
C-DC-24-1	E-glass / epoxy	4.4	56,726	835	3,194	3.83	0.474	**0.487**	**-2.7%**	0.852	-44.4%	Corrosion interaction (40% deep)
C-GW-24-1	E-glass / epoxy	4.4	104,206	843	1,221	1.45	0.477	**0.487**	**-2.1%**	0.852	-44.0%	Girth weld interaction
D-PD-24-1	Carbon / epoxy	9.7	101,151	833	722	0.87	0.361	0.221	63.4%	0.387	-6.6%	
D-DC-24-1	Carbon / epoxy	9.7	101,151	834	768	0.92	0.552	0.221	149.9%	0.387	42.8%	Corrosion interaction (40% deep)
E-PD-24-1	Carbon / epoxy	10.3	108,107	837	453	0.54	0.341	0.208	63.9%	0.364	-6.3%	
E2-PD-24-1	Carbon / epoxy	10.3	102,000	877	1,033	1.18	0.333	0.208	60.1%	0.364	-8.5%	
E2-PD-24-2	Carbon / epoxy	12.6	102,000	877	1,128	1.29	0.303	0.170	78.2%	**0.298**	**1.8%**	*Good performance / optimized*
MATR-3-5 Data (12.75-inch x 0.188-inch, Grade X42 pipe | cycled from 100 to 890 psi, ΔP = 64% SMYS | Average residual dent depth of 4.7% | 250,000 cycle rnuout)												
A-PD	E-glass / urethane	3.0	215,271	890	1,872	2.10	0.459	0.476	-3.5%	0.833	-44.9%	
B-PD	E-glass / epoxy	2.0	157,351	890	1,821	2.05	0.409	0.714	-42.7%	1.249	-67.3%	System under-designed
C-PD	E-glass / rigid coil	4.0	250,000	890	1,049	1.18	0.658	0.357	84.4%	0.625	5.4%	This always system has same thickness
D-PD	Carbon / epoxy	7.0	250,000	890	573	0.64	0.439	0.204	115.3%	**0.357**	**23.0%**	*Good performance / slightly over-designed*
E-PD	E-glass / urethane	2.6	47,661	890	2,327	2.61	0.578	0.543	6.5%	0.950	-39.1%	System did not test well (disregard data)
F-PD	Carbon / urethane	5.5	47,299	890	1,679	1.89	0.389	0.260	49.3%	0.456	-14.7%	System did not test well (disregard data)
G-PD	Carbon / epoxy	7.0	186,452	890	960	1.08	0.29	0.204	42.2%	0.357	-18.7%	System under-designed
H-PD	E-glass / epoxy	4.4	250,000	890	723	0.81	0.365	**0.324**	**12.5%**	0.568	-35.7%	*Good performance / slightly over-designed*
I-PD	Steel / epoxy	30.0	250,000	890	708	0.80	0.202	0.048	324.5%	0.083	142.6%	
J-PD	E-glass / urethane	2.6	250,000	890	1,296	1.46	1.281	0.545	135.1%	0.953	34.3%	
Unrepaired	N/A	N/A	10,249	890	4,537	5.10	N/A	N/A	N/A	N/A	N/A	Unrepaired: No repair installed

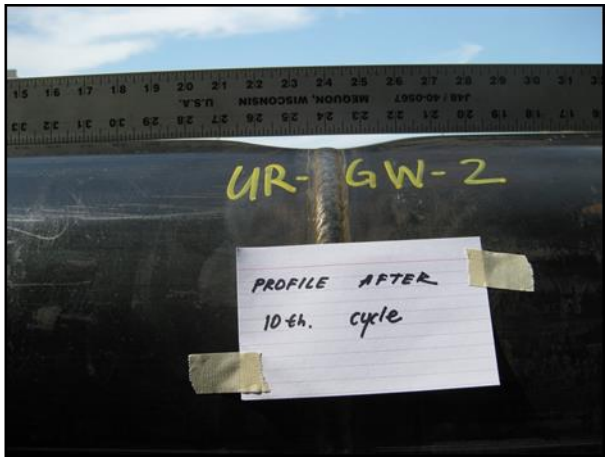
Composite Qualification Design Flowchart

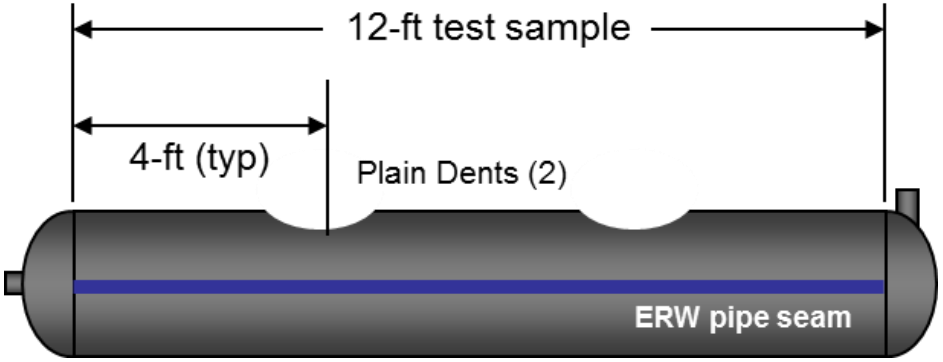


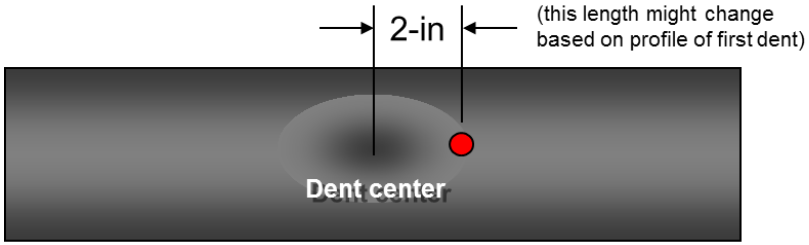
Equation Validation Process

- Two studies: MATR-3-5 and DV-CIP
- Pipe D/t ratios ranging from 34 to 96
- Number of dents
  - 25 repaired
  - 2 unrepaired
- No effective means to numerically account for filler material (at the present time)
- Data showed that performance of carbon-reinforced systems cannot be determined by modulus alone

Prescriptive Testing Methods







Close-up View of Dented Region

Looking Forward

- Reinforcement of cracks using composite materials
- Finite element modeling to optimize repairs for critical applications
- Moving beyond corrosion and dents; providing reinforcement for bends, tees, and other features
- Need to better understand elevated temperature performance (i.e. loss of strength)
- Joint industry studies a huge plus for the industry
- Continued work with PRCI (NEW: BSEE & PHMSA)

All of the above items were listed last year; we are now doing them!

Thank You!