Composite Repair Technology and Its Application to Pipeline Integrity

Presentation to the PHMSA R&D Forum

Marriot Crystal City ● Thursday, June 25, 2009

Presentation by Dr. Chris Alexander (Stress Engineering Services, Inc.)

Taking on your toughest technical problems

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Presentation Topics

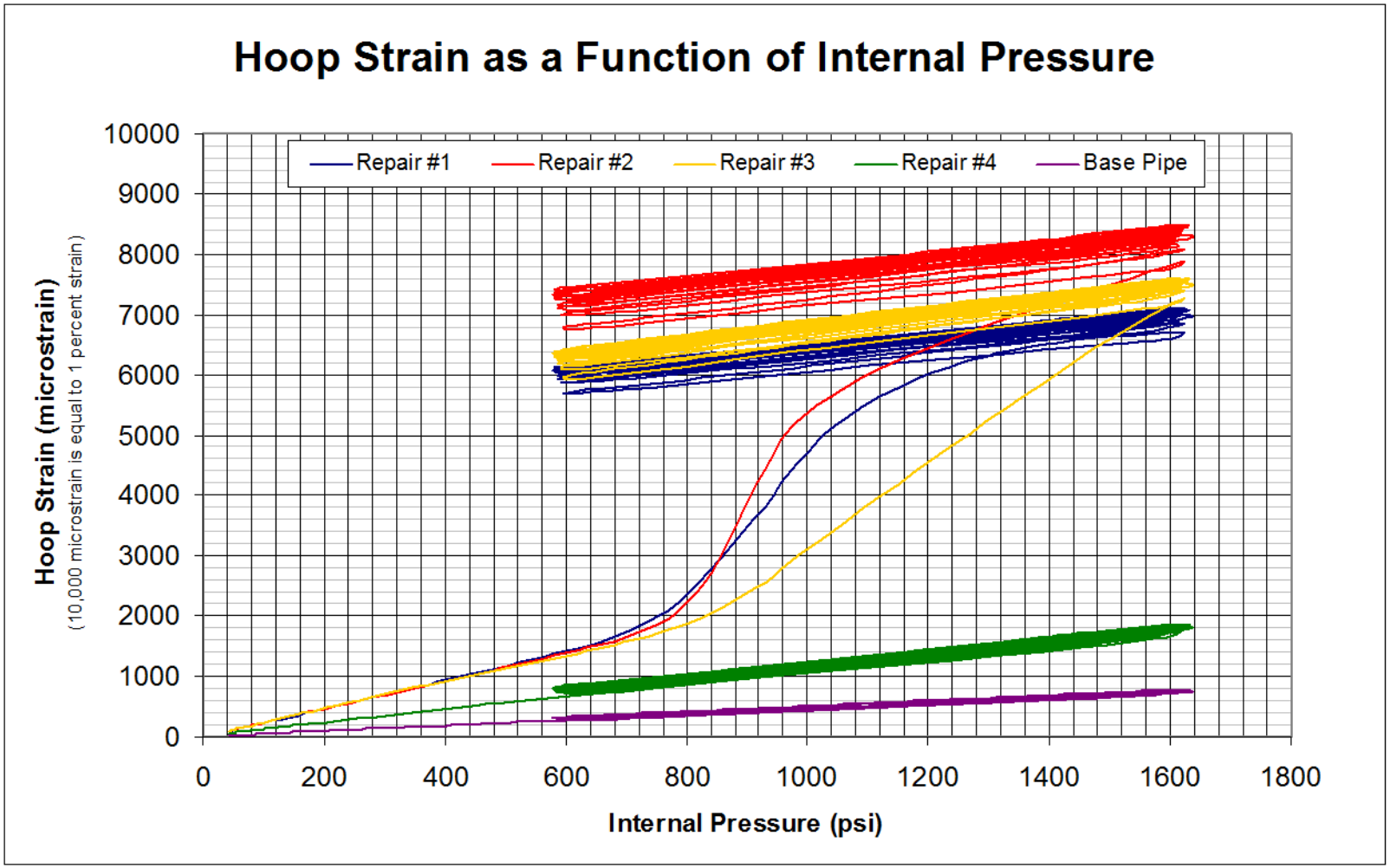
- Composite technology case studies
  - Severe corrosion subject to cyclic pressures
  - Mechanical damage
  - Repair of pipe fittings
  - Pipe bending (offshore riser)
  - Wrinkle bends
  - Pipeline re-rating using composite materials
- Future considerations

Fatigue Evaluation

(Severe corrosion subject to cyclic pressure)

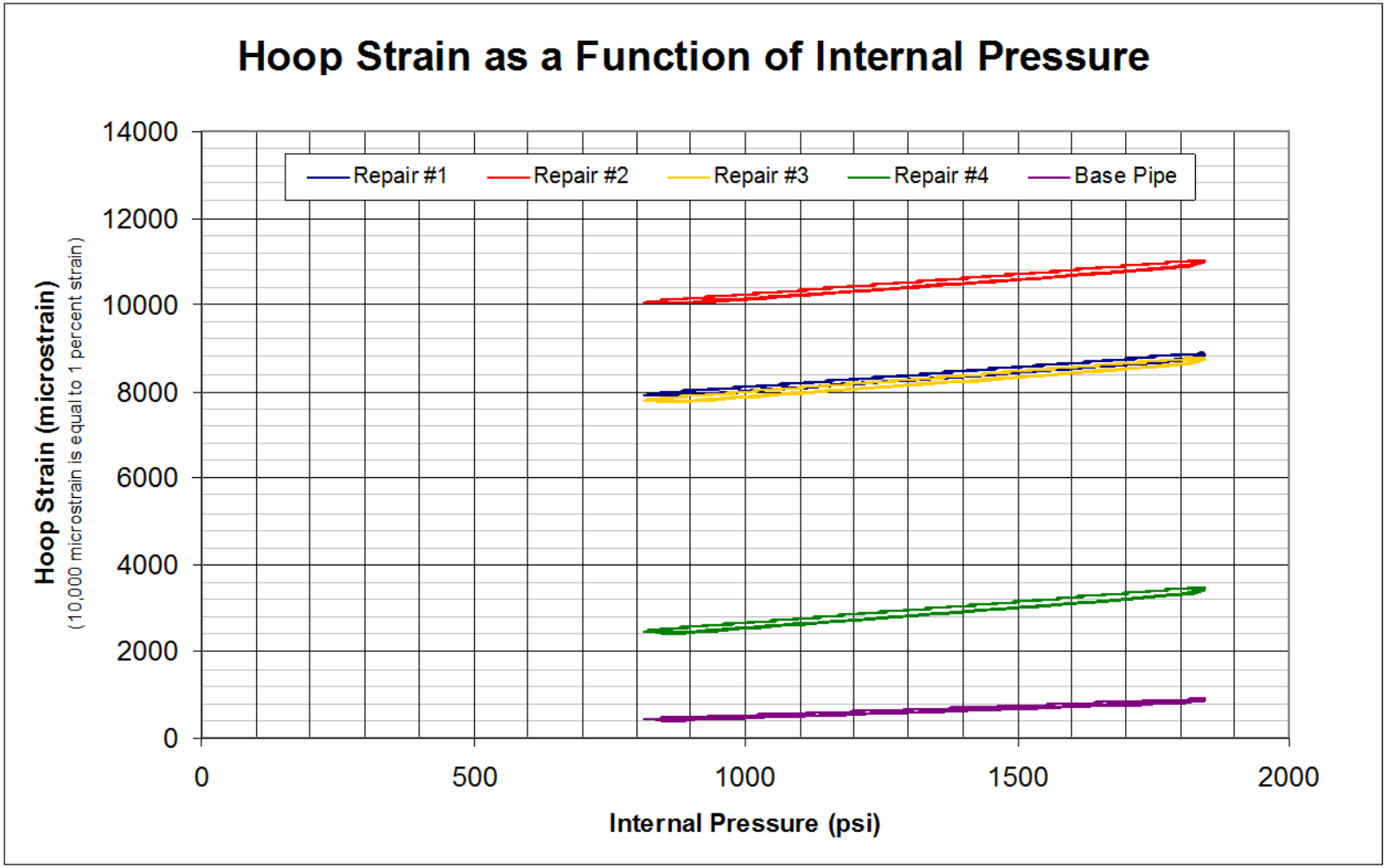
- Repair of 12.75-inch x 0.375-inch, Grade X42 pipe with 75% corrosion
- Strain gages installed beneath repair to monitor strain during pressure cycling
- Pressure range: ΔP = 890 – 1780 psi (36% SMYS)
- Five different systems cycled to failure:
  - System #1 (E-glass): 43,090 cycles
  - System #2 (E-glass): 72,920 cycles
  - System #3 (E-glass): 140,160 cycles
  - System #4 (E-glass): 165,120 cycles
  - System #5 (Carbon): 532,776+ cycles (no failure recorded)

Strain Gage Results (Start-up)



75% corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe
cycled at ΔP = 36% SMYS

Strain Gage Results (150,000 cycles)



75% corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe
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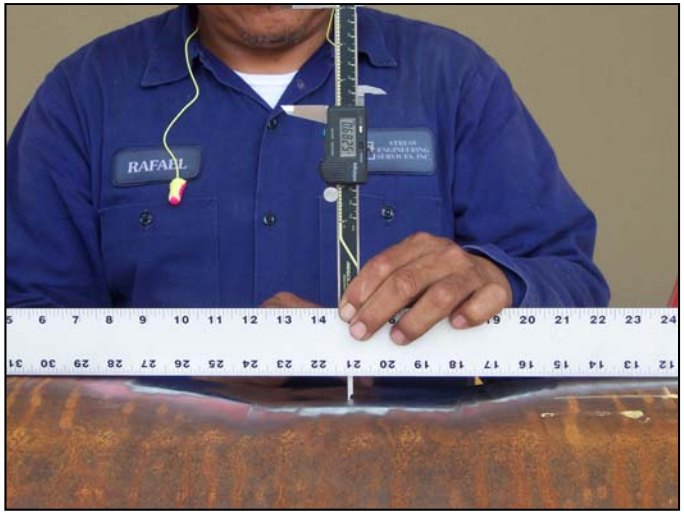
Repair of Mechanical Damage (1/2)



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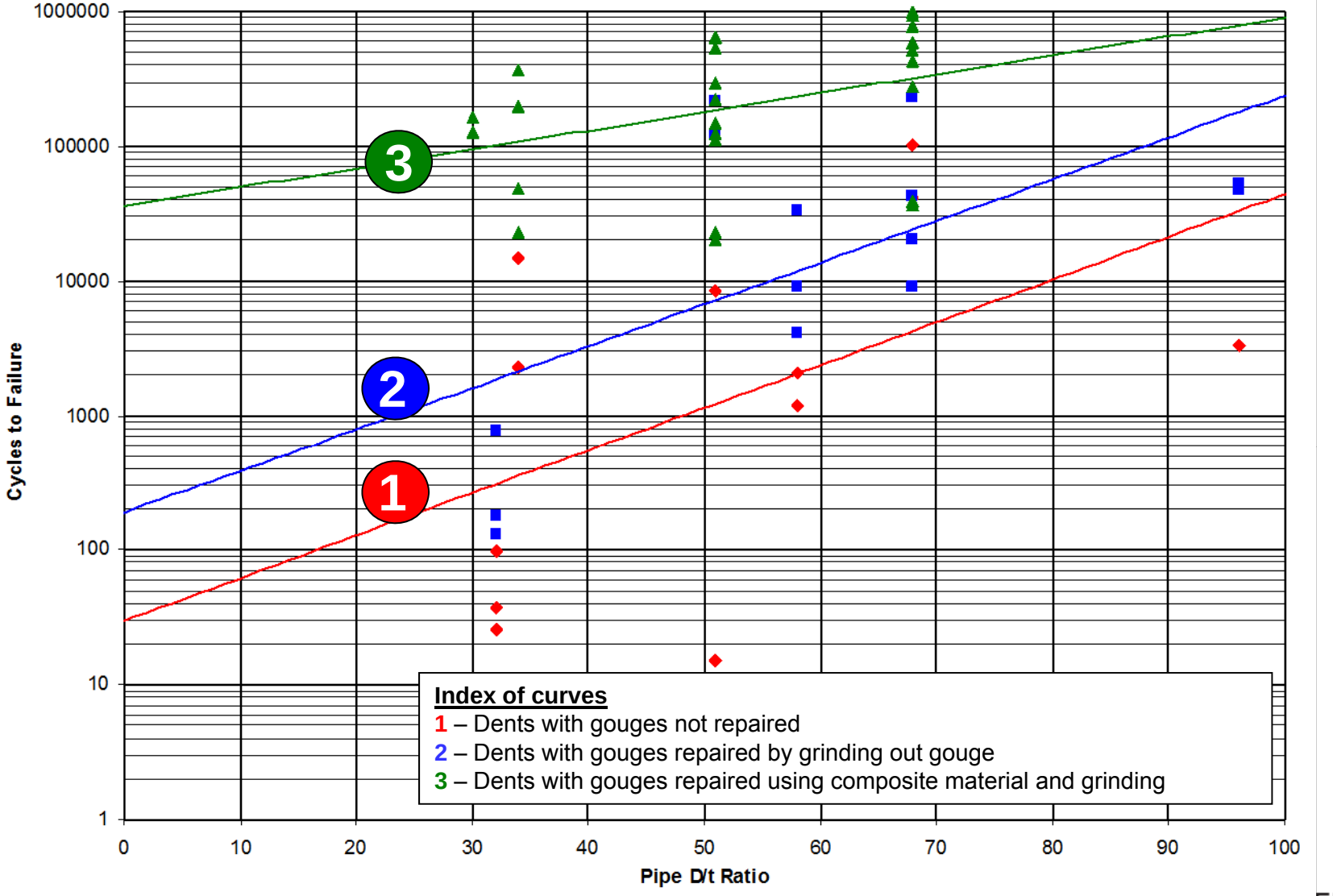
Repair of Mechanical Damage (2/2)

Mechanical Damage Fatigue Testing

(Results for Clock Spring, Armor Plate Pipe Wrap, Aquawrap, and Pipe Wrap A+ similar)



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Repair of Pipe Fittings

Results from Armor Plate Pipe Wrap test program involving 12.75-inch x 0.375-inch, Y52 elbow and tee pipe fittings with machined 50% corrosion –operating pressure is 1,778 psi

12-in STD Elbow (50% corrosion)

Unrepaired: 2,610 psi

Repaired: 4,625 psi

12-in STD Tee (50% corrosion)

Unrepaired: 3,059 psi

Repaired: 4,617 psi

Failures in repaired fittings occurred outside repairs in base pipe.
(Composite thickness of 0.563 inches for both repairs)

Resulting design margin of 2.6+ for both repairs

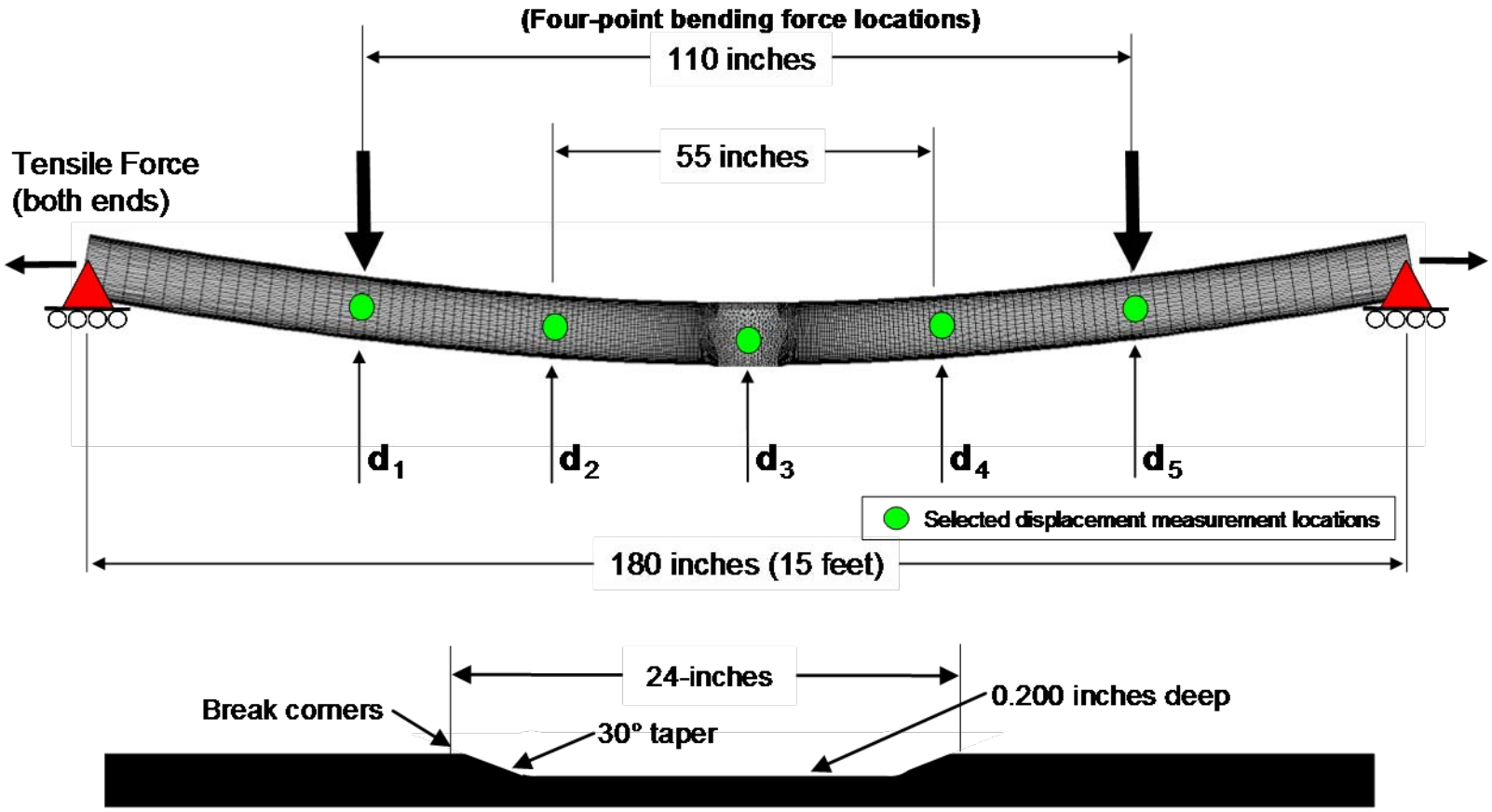
Bend Testing Study

- Full-scale testing using 8.625-in x 0.406-in, Grade X46 pipe (representative D/t ratio for risers)
- Three test samples integrating 50% deep 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 on test samples beneath repairs
- In testing limit analysis methods used to capture the lower bound plastic collapse load

NOTE: Test load variables shown in **BOLD RED** are the ones incrementally increased to capture the corresponding lower bound collapse load.

Testing Details

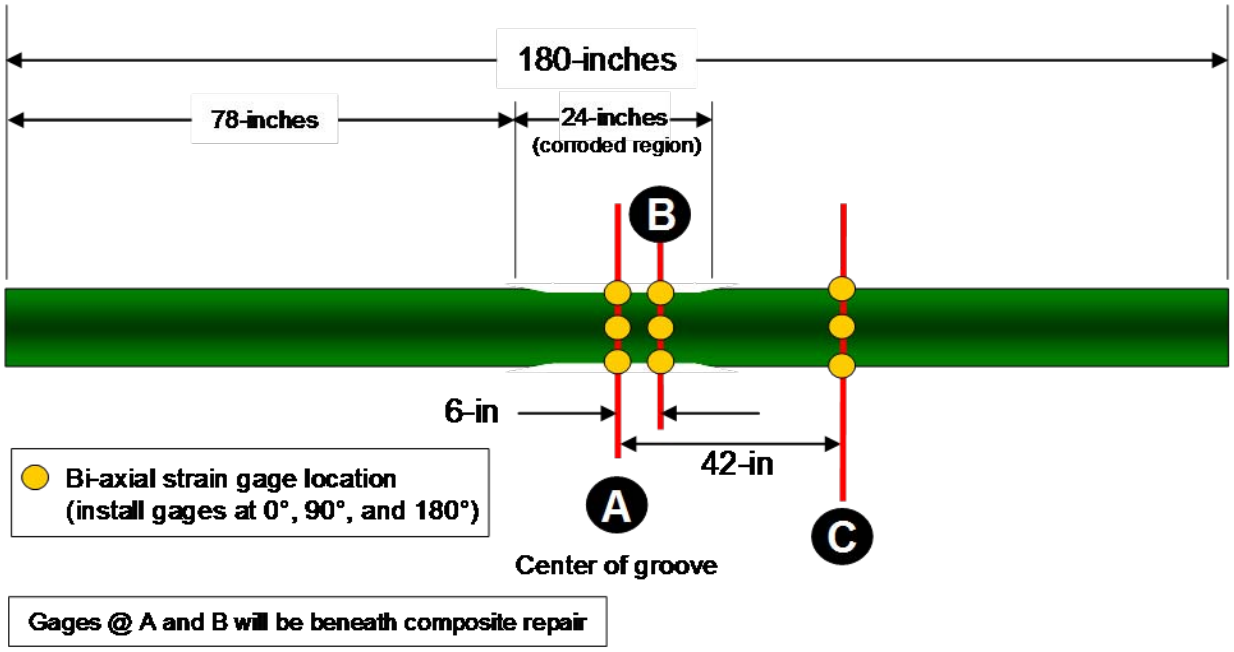
(Sample loading and defect configuration)

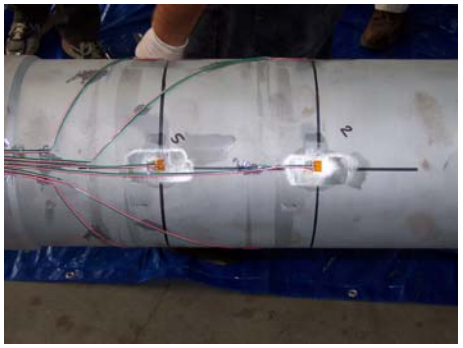


Simulated corrosion on outside surface of pipe (circumferential groove)

Testing Details

(Strain gage details – 12 per sample)





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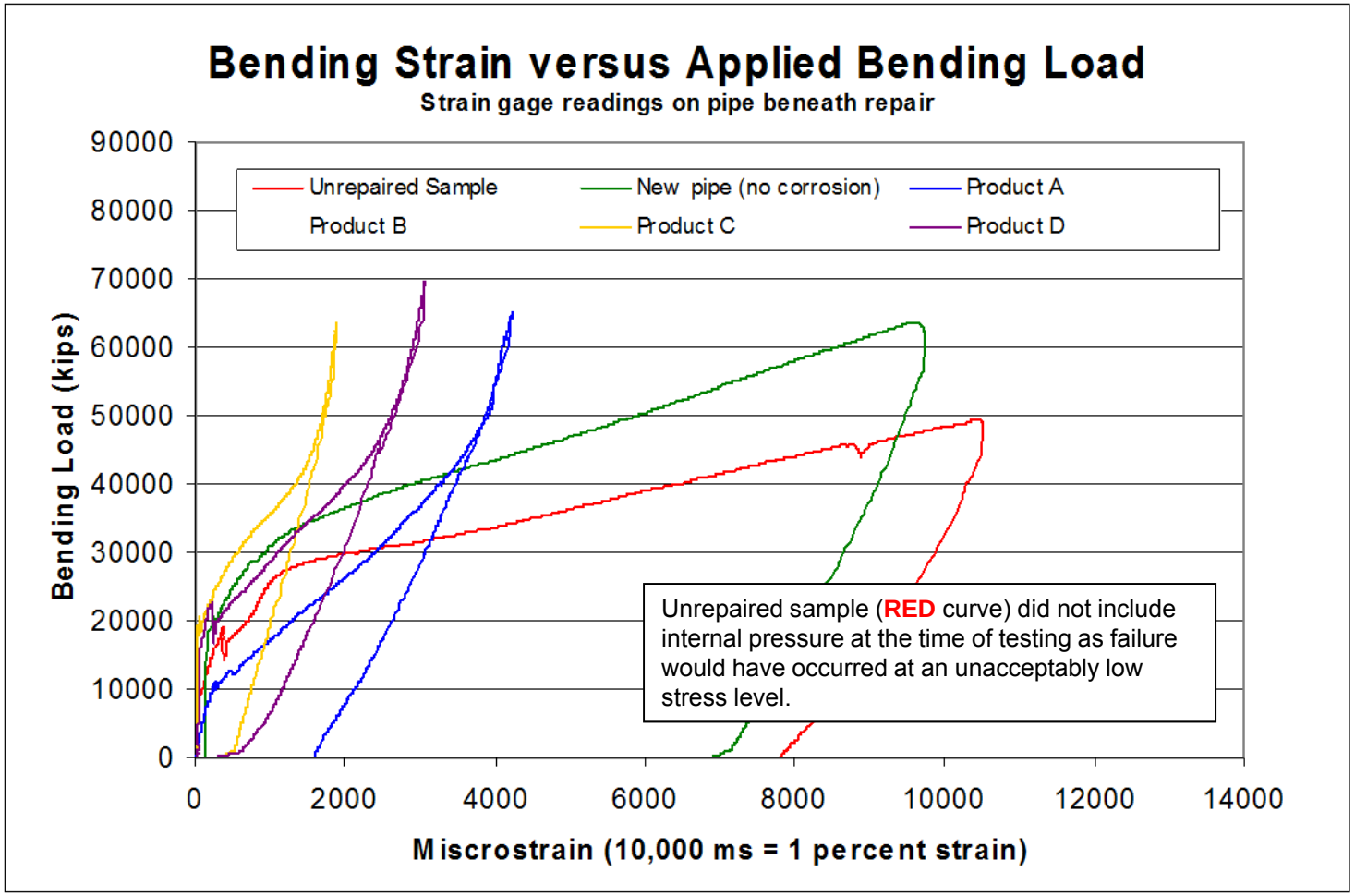
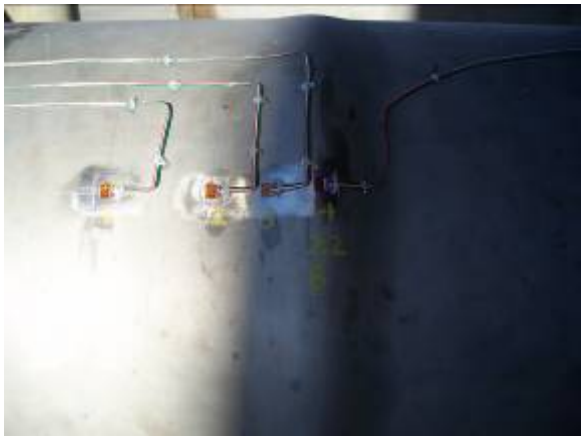
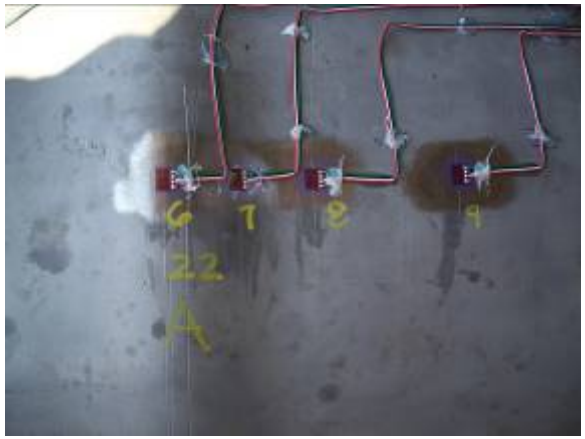
Test Results
(Bending load sample)

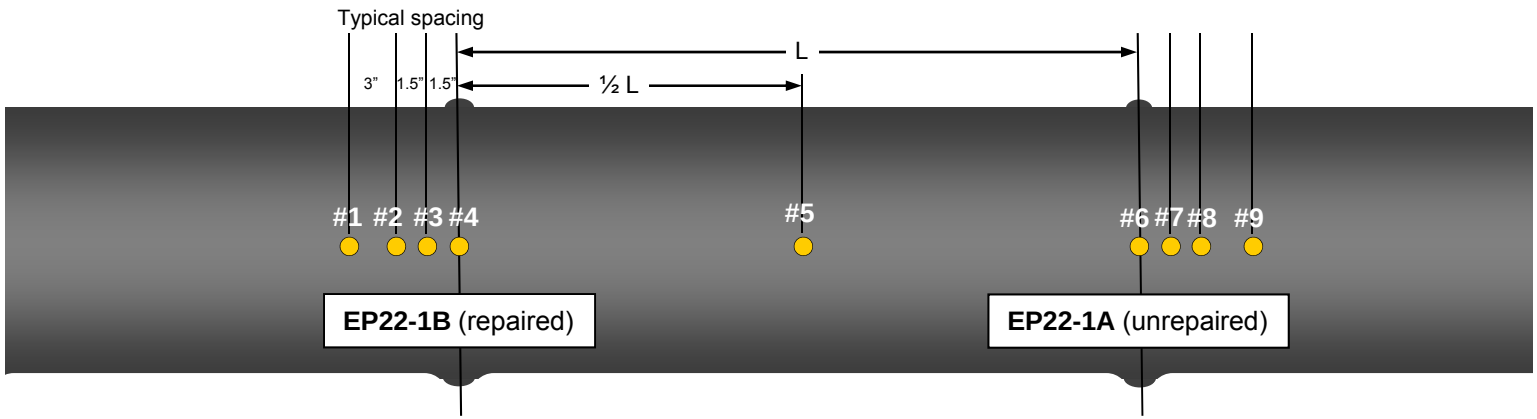


Testing loads included bending, tension (145 kips), and internal pressure (2880 psi)

Wrinkle Bend Test Program
(Photos from Test Set-up)







El Paso Wrinkle Bend Samples
(Samples EP22-1A and EP22-1B)

Strain Gage Results

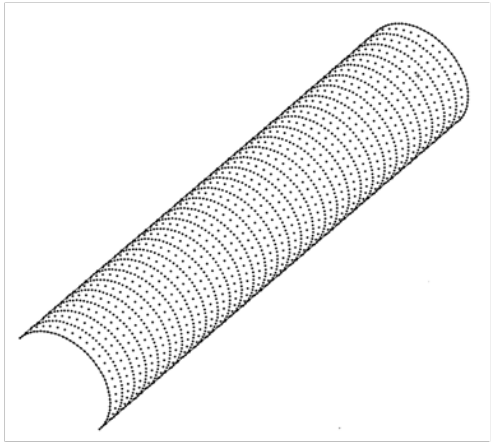
Sample	Condition	Peak of Wrinkle (Axial)		3 inches from Wrinkle (Axial)	
		De (me)	Dσ (ksi)	De (me)	Dσ (ksi)
EP22-1A (unrepaired)	Wrinkle in seam weld	1190	36	979	29
EP22-1B (repaired)	Wrinkle in seam weld	820	25	703	21
Percent reduction due to composite		31 percent		28 percent	
EP22-2A (unrepaired)		954	29	1096	33
EP22-2B (repaired)		757	23	868	26
Percent reduction due to composite		21 percent		21 percent	
EP30-1A (unrepaired)	40 percent corrosion	1960	59	1321	40
EP30-1B (repaired)	40 percent corrosion	1259	38	1213	36
Percent reduction due to composite		36 percent		8 percent	

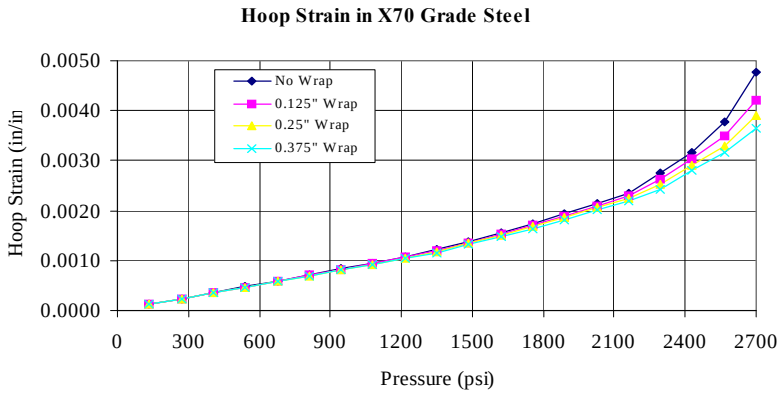
Fatigue Test Results

Sample Number	Pipe Geometry	Grade	Condition	ΔP (psi) (min to max)	Cycles	Notes
EP30-1A	30-inch x 0.312-inch	X52	Unrepaired (40% corrosion)	100-779	19,252	Crack developed in center of wrinkle
EP30-1B	30-inch x 0.312-inch	X52	Repaired (40% corrosion)	100-779	41,171	Crack developed beneath APPW repair
EP22-1A (weld)	22-inch x 0.312-inch	X42	Unrepaired	100-858	42,818	Crack developed in center of wrinkle
EP22-1B (weld)	22-inch x 0.312-inch	X42	Repaired	100-858	55,371	Longitudinal crack developed outside of repair
EP22-2A	22-inch x 0.312-inch	X42	Unrepaired	100-858	93,135	Crack developed in bosset weld (test aborted)
EP22-2B	22-inch x 0.312-inch	X42	Repaired	100-858	93,135	Crack developed in bosset weld (test aborted)

Re-rating Pipelines

- Idea is to use composite materials to re-rate design pressure of pipelines
- Analysis and testing required to ensure that service conditions can be met
- Primary driver is class location changes
- Originally studied in 1999





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Future Considerations

- Failure to consider limited fatigue life of extreme corrosion repairs could be problematic (must consider performance testing to prove capacity)
- A large database is being generated for repair of both corrosion and dents considering composite materials
- Data also available on wrinkle bend repairs as well as repaired corrosion samples subjected to axial tension and bending loads
- Ongoing research should be used as basis to determine acceptable composite repair usage