Current Testing Results and Validation of the Tyfo® Fibrwrap® Systems for Pipeline Rehabilitation

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AEGION®

Stronger. Safer. Infrastructure.™

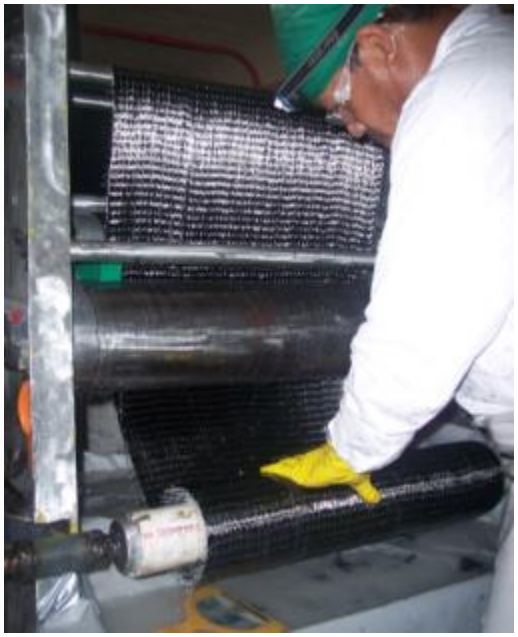
Insituform® FYFE® FIBRWRAP® MTC™

Testing Programs Recently Completed

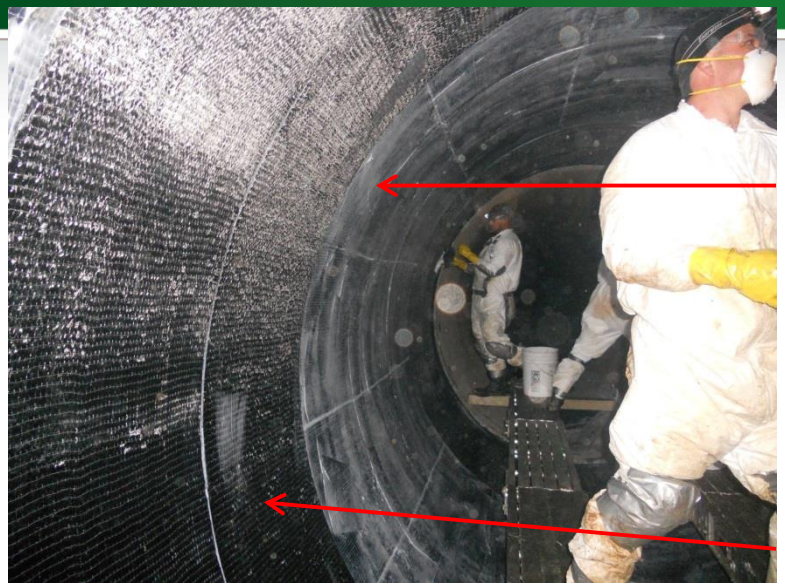
- Watertightness Testing at SGH Pressure Chamber for Improved Detailing
- Defect Criticality Testing at SGH Pressure Chamber to Understand the Structural Significance of Typical Cosmetic Anomalies
- Aerospace Durability Testing on the Tyfo Systems to Understand the Properties after 50-to-100 Years of Exposure
- Aerospace Durabiltiy Report on Specimens Exposed to 15-years at the Yolo Causeway
- Tensile Testing from In-Service Materials Taken after 18-years of Environmental Exposure

Saturation and Application

CFRP Installation



Impregnate Carbon Fiber fabric with Epoxy



Longitudinal layer

Circumferential layer

Watertightness layer

SIMPSON GUMPERTZ & HEGER

Engineering of Structures and Building Enclosures

Tyfo® SEH Systems – Glass Systems

- Glass Fibers
  - Tyfo® SEH-51A
  - Tyfo® WEB
- Epoxies
  - Tyfo® S Epoxy
  - Tyfo® SW1S Epoxy
  - Tyfo® S-T Epoxy
  - Thickened Tyfo® S and Tyfo® S-T Epoxies

Tyfo® SEH-51A

Tyfo® WEB

Tyfo SCH Systems – Carbon Systems

- Carbon Fibers
  - Tyfo® SCH-41
  - Tyfo® SCH-41-2X
  - Tyfo® SCH-Mark V
  - Tyfo® SCH-11UP
- Epoxies
  - Tyfo® S Epoxy
  - Tyfo® SW1S Epoxy
  - Tyfo® S-T Epoxy
  - Thickened Tyfo® S and Tyfo® S-T Epoxies

Tyfo® SCH-41

Tyfo® SCH-Mark V

Watertightness Test Apparatus at SGH

- Introduce a watertight layer in the layup
- Test the laminate
  - Pressurize laminate over approximate 1 ft opening with 96 in. diameter curvature
  - Test laminate to 400 psi min

Watertightness Validation Testing

Tyfo® Fibrwrap ® Systems retain water tightness characteristics to pressures beyond 400 psi and up to rupture strain.

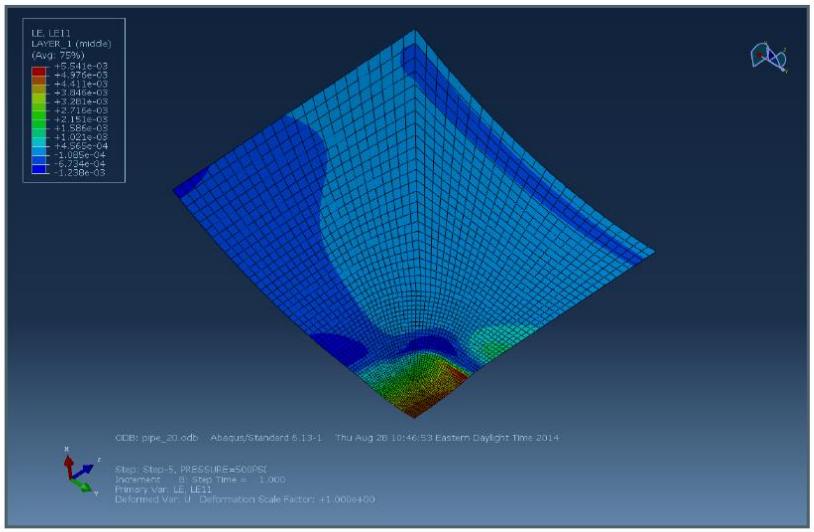
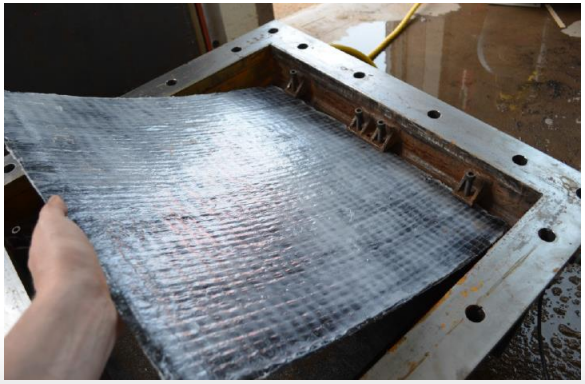
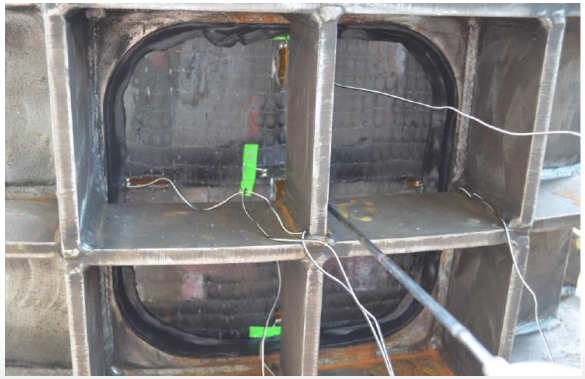


Figure 3 – Strains in the fiber direction of the inner layer of CFRP at 500 psi pressure. Note maximum strain of 0.55 percent.





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Engineering of Structures and Building Enclosures

Watertightness (Round 2) Testing

Table 1 – Summary of Test Results

Specimen #	Description	Materials	Pressure at Leak (psi)	Max. Strain Percent
1	1L+1G 1H L and H = 0.08 in. CFRP G = thin layer of woven glass fabric	CFRP system with 0.08 in. lamina and Proprietary woven glass fabric	Visible cracking of thickened epoxy between fiber bundles at 275 psi. 0.025 in. wide crack at 500 psi. No weepage at 500 psi.	0.96
2	Same as Specimen 1	Same as Specimen 1	Visible cracking of thickened epoxy between fiber bundles at 175 psi. 0.013 in. wide crack at 400 psi. Minor weepage through crack in thickened epoxy at 450 psi. Weepage unchanged at 500 psi.	0.97 and 1.20
3	1L+1G 1H L and H = 0.04 in. CFRP G = thin layer of woven glass fabric	CFRP System with 0.04 in. Lamina and Proprietary Glass Fabric	Visible cracking of thickened epoxy between fiber bundles at 175 psi. 0.022 in. wide crack at 225 psi. No weepage prior to rupture. Laminate ruptured at 300 psi.	1.19

Watertightness (Round 1) Testing

Sample Tested			Date Tested In 2014	Max Pressure (psi)	Percent Cure at Testing	Max Strain at Center of CFRP(%)	Failure Mode
R	Spec. No.	Lay up					
1	3	2L+1H+2L	21-Jul-	375	95.1	0.70	Sample cured beyond 95% leaked and ruptured at 375 psi.
	4	2L+1H+1G+2L	22-Jul-	426	95.1	0.84	No failure, unloaded after reaching 426 psi.
2	3	2L+1H+2L	30-Jul-	276	90.9	0.69	Small leak developed through crack in CFRP
	4	2L+1H+1G+2L	30-Jul-	450	90.9	0.78	No failure, unloaded after reaching 450 psi, small amount of delamination.
3	1	1L+1 H	26-Aug	251	86.7	0.54	Sample leaked and burst at above 250 psi.
	2	1L+1G+1H	26-Aug	400	86.7	0.78	No failure, unloaded after reaching 400 psi.

Specimen #	Layup	Materials
1	1L + 1 H	2X
2	1L + 1G + 1H	2X and Glass
3	2L + 1H + 2L	1X
4	2L + 1H + 1G + 2L	1X and Glass

Hand Layup Anomalies

- The imperfections below are the most typical of those seen during inspections of previously applied CFRP
  - Blisters / Voids
  - Wrinkles (misaligned fiber strands)
  - Fiber Separation (gaps at butt splice)
  - Insufficient Epoxy Top Coat

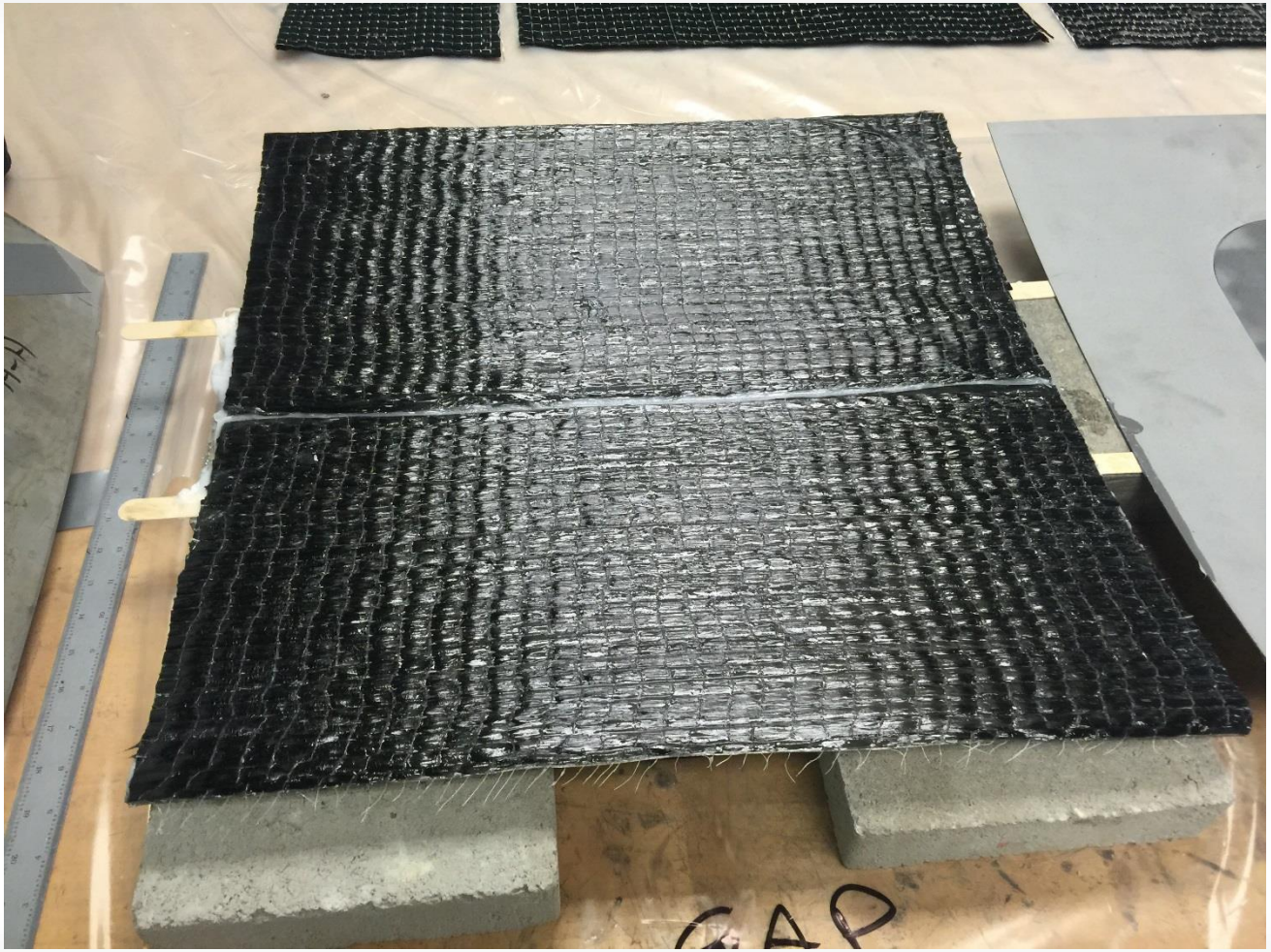
Hand Layup Anomalies (continued)

- Typical projects have an affected surface area <0.5% of the total installed surface area
- Question: Are these anomalies affecting the long term lifespan of the installed Tyfo Systems?
  - Department of Defense's Composite Materials Handbook allows for defects of <1% of the surface area in fracture critical aircraft
  - No current guidelines in AWWA Standard for CFRP or third party testing*

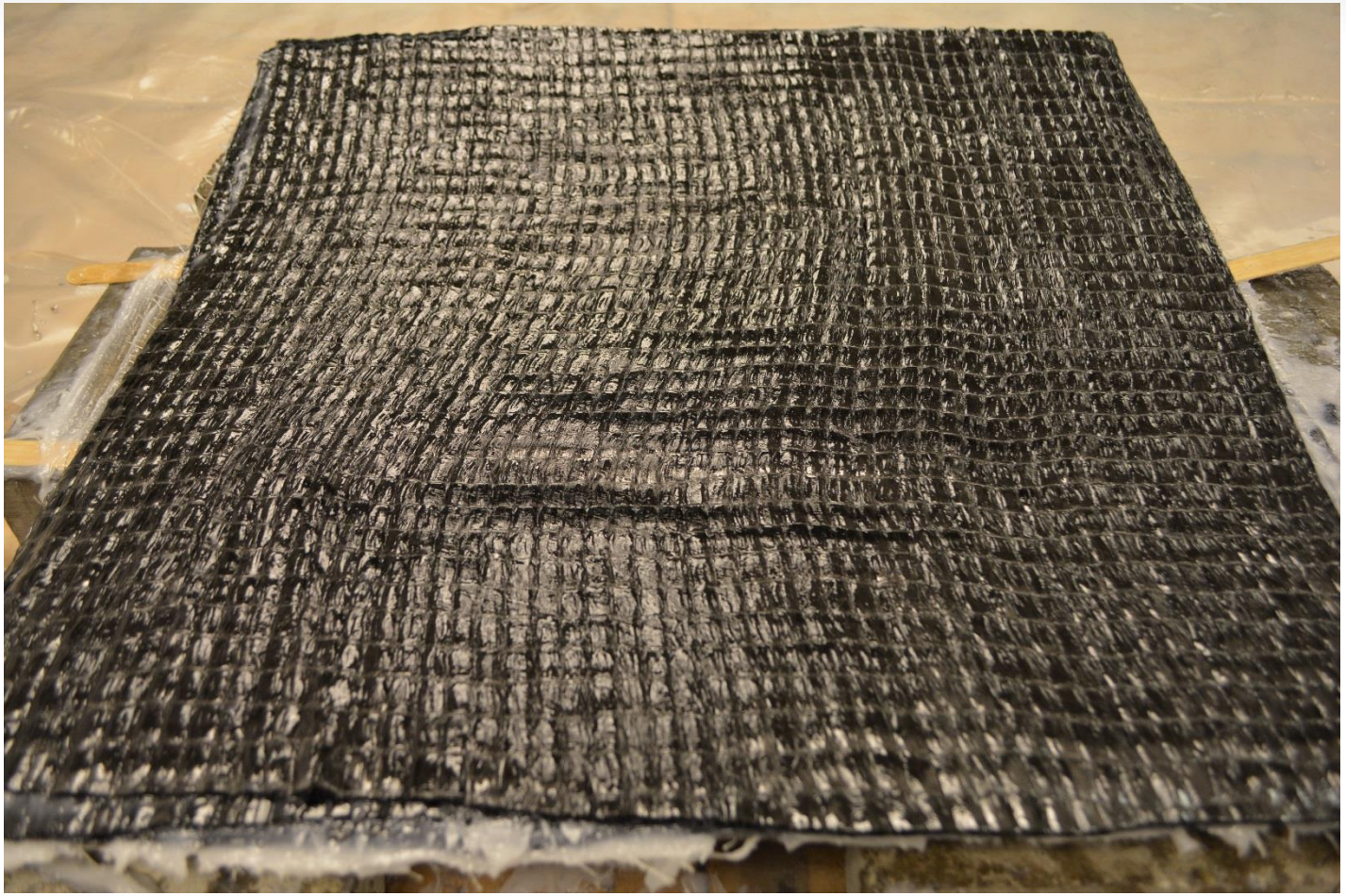
*New AWWA CFRP Standard Pending

Test Specimen Preparation

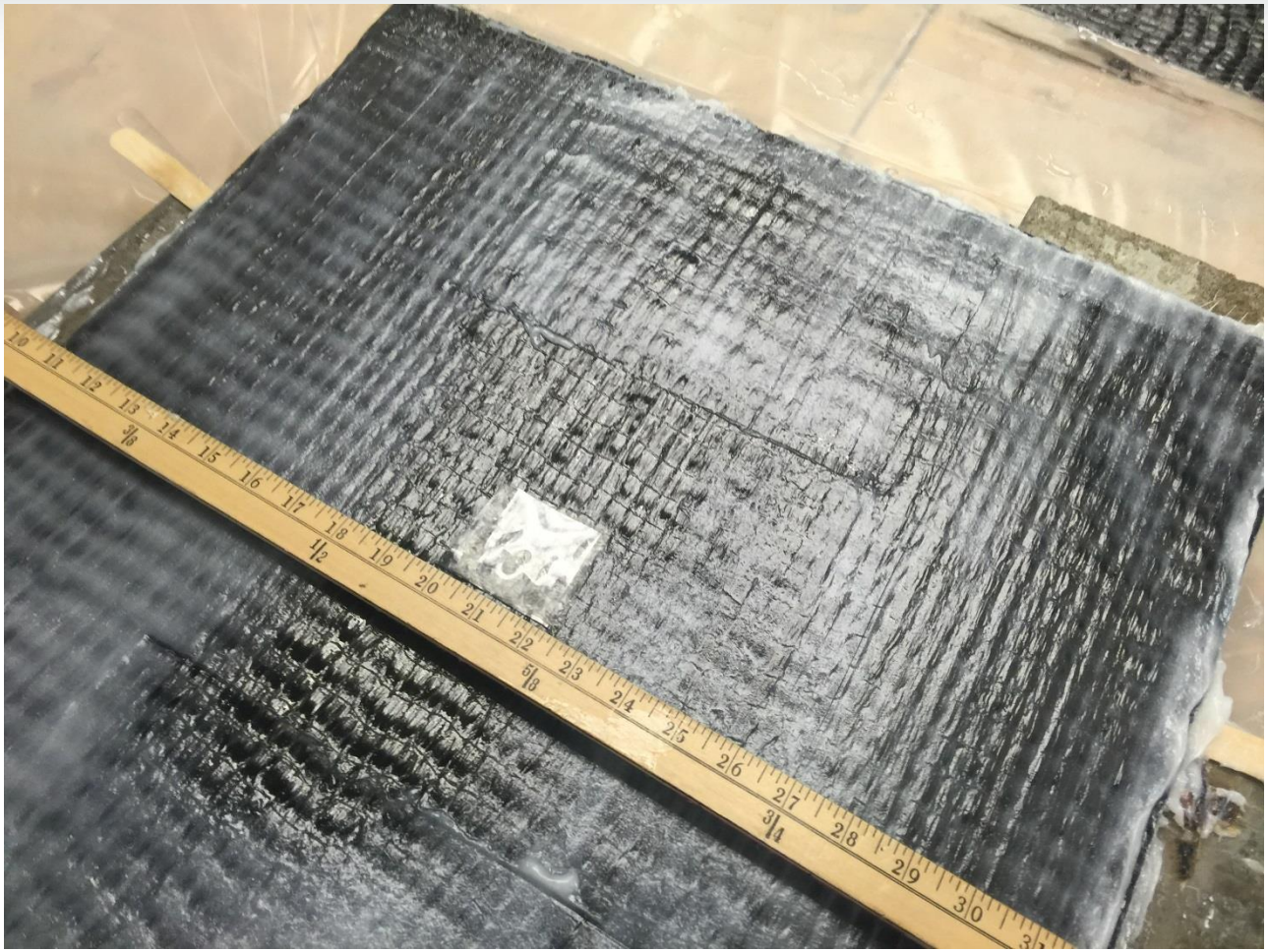
Gap (Insufficient Butt-Splice Tolerance) Imperfection



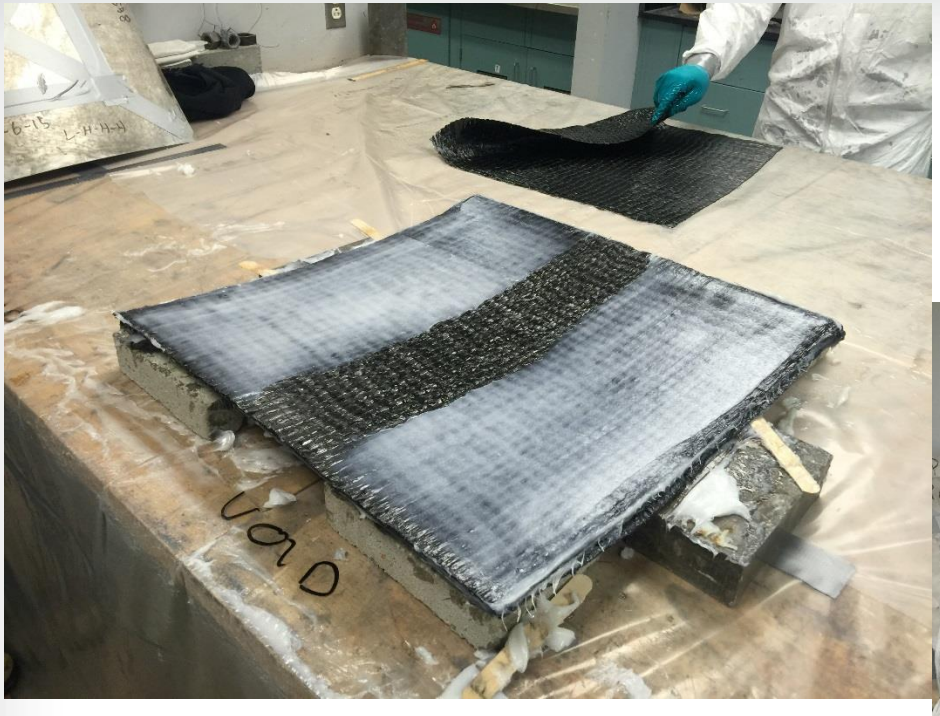
Waviness Imperfection



Void Imperfection



Improper Fabric Saturation Imperfection



Defect Criticality Testing (Phase 1)

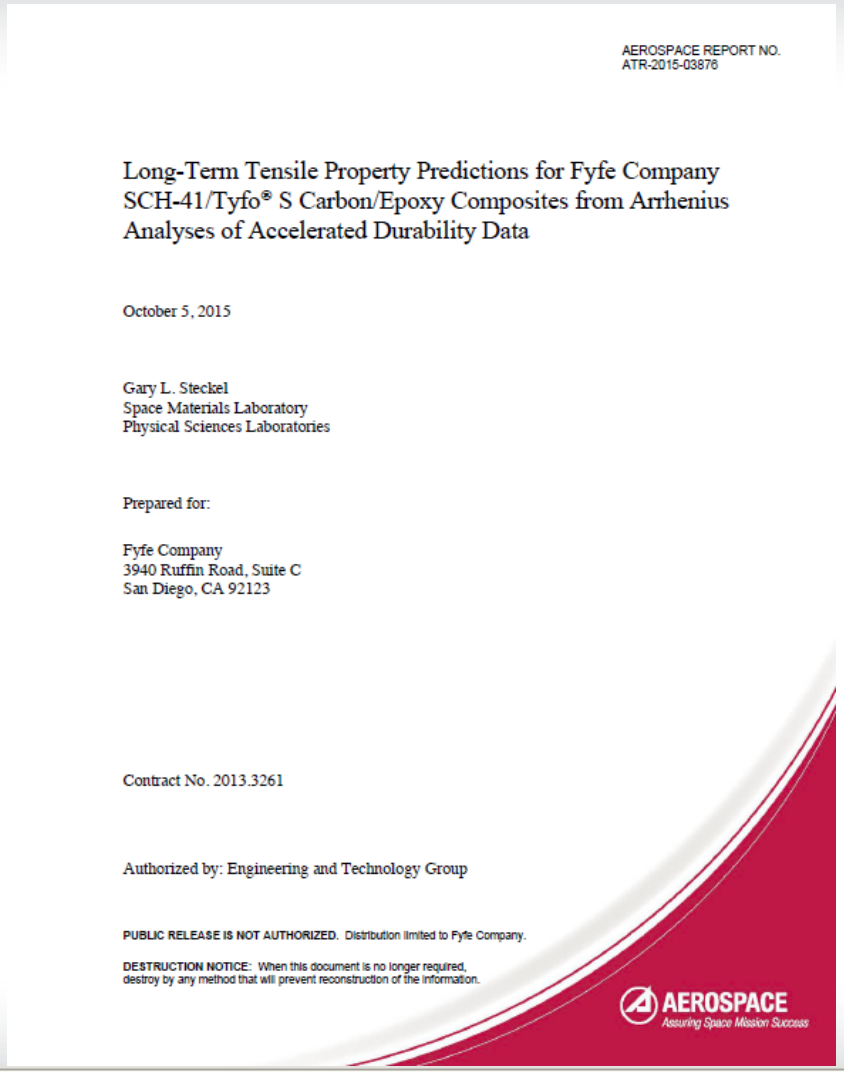
Table 1 – Summary of results

Specimen	Pressure and Observations	Max. Recorded Hoop Strain
Control specimen	First weep through laminate at 200 psi, leak with continuous water stream at 225 psi, test terminated at 250 psi	0.43% at 250 psi
Specimen with "gap" imperfection	First weep through laminate at 100 psi, multiple weep locations at 200 psi, test terminated at 225 psi	0.43% at 171 psi*
Specimen with "void" imperfection	First weep through laminate at 425 psi, test terminated at 450 psi	0.39% at 172 psi*
Specimen with "improper fabric saturation" imperfection	First weep within the improperly saturated zone at 350 psi, increased weep with continuous water stream at 400 psi, test terminated at 450 psi	0.44% at 201 psi*
Specimen with "waviness" defect imperfection	Weep at multiple locations at 425 psi, test terminated at 425 psi	0.44% at 177 psi*

* The strain gage measuring the maximum hoop strain was damaged because of epoxy cracking at the pressure shown and did not yield reliable data at higher pressures.

Void Imperfection Inspection After Testing

Aerospace Accelerated Durability Testing



AEROSPACE REPORT NO.
ATR-2015-03876

Long-Term Tensile Property Predictions for Fyfe Company SCH-41/Tyfo® S Carbon/Epoxy Composites from Arrhenius Analyses of Accelerated Durability Data

October 5, 2015

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Contract No. 2013.3261

Authorized by: Engineering and Technology Group

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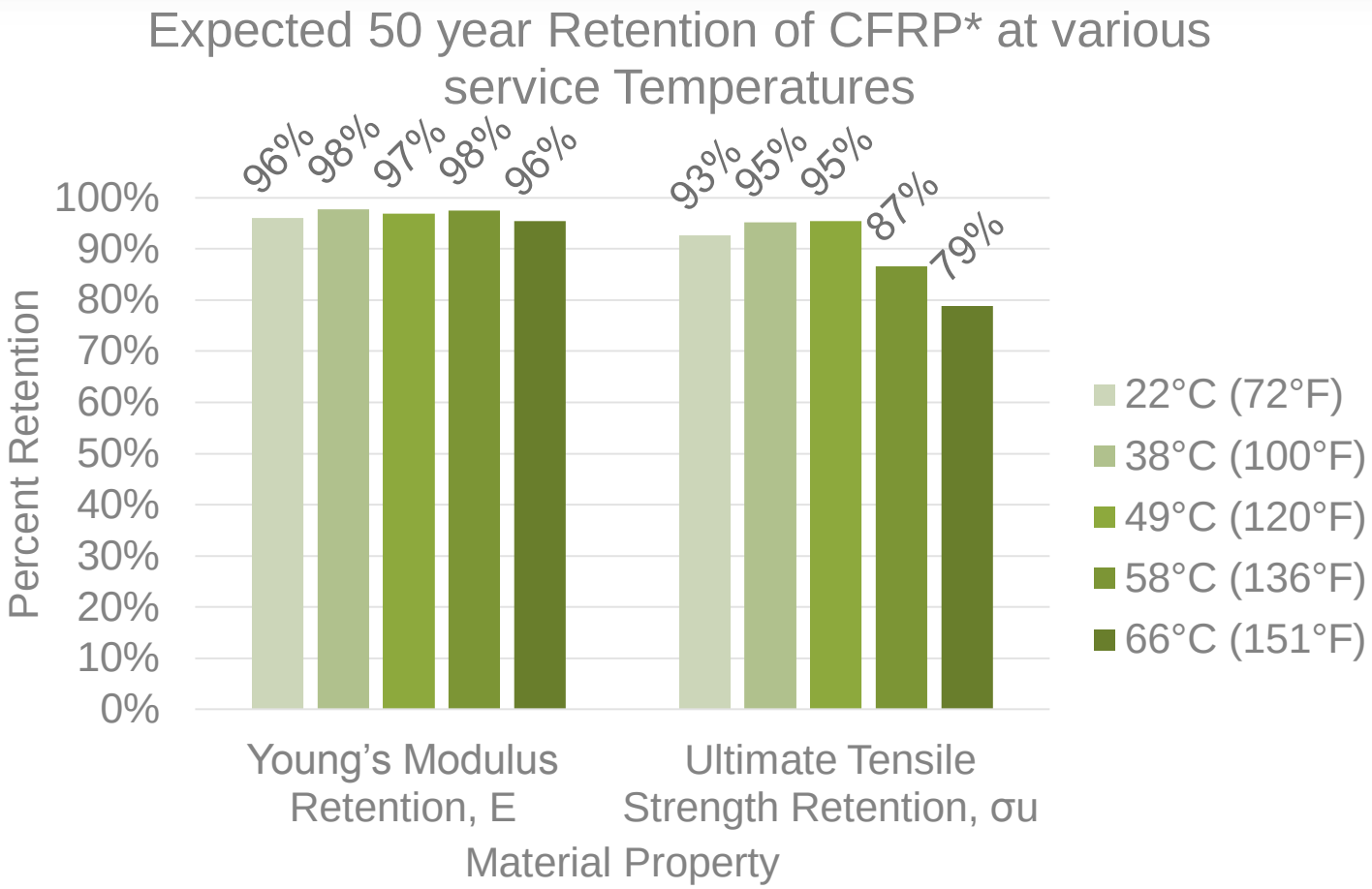
Accelerated Aging Testing Using the Arrhenius Model



Tyfo SCH-41 System Panels on the Yolo Causeway

October 1998

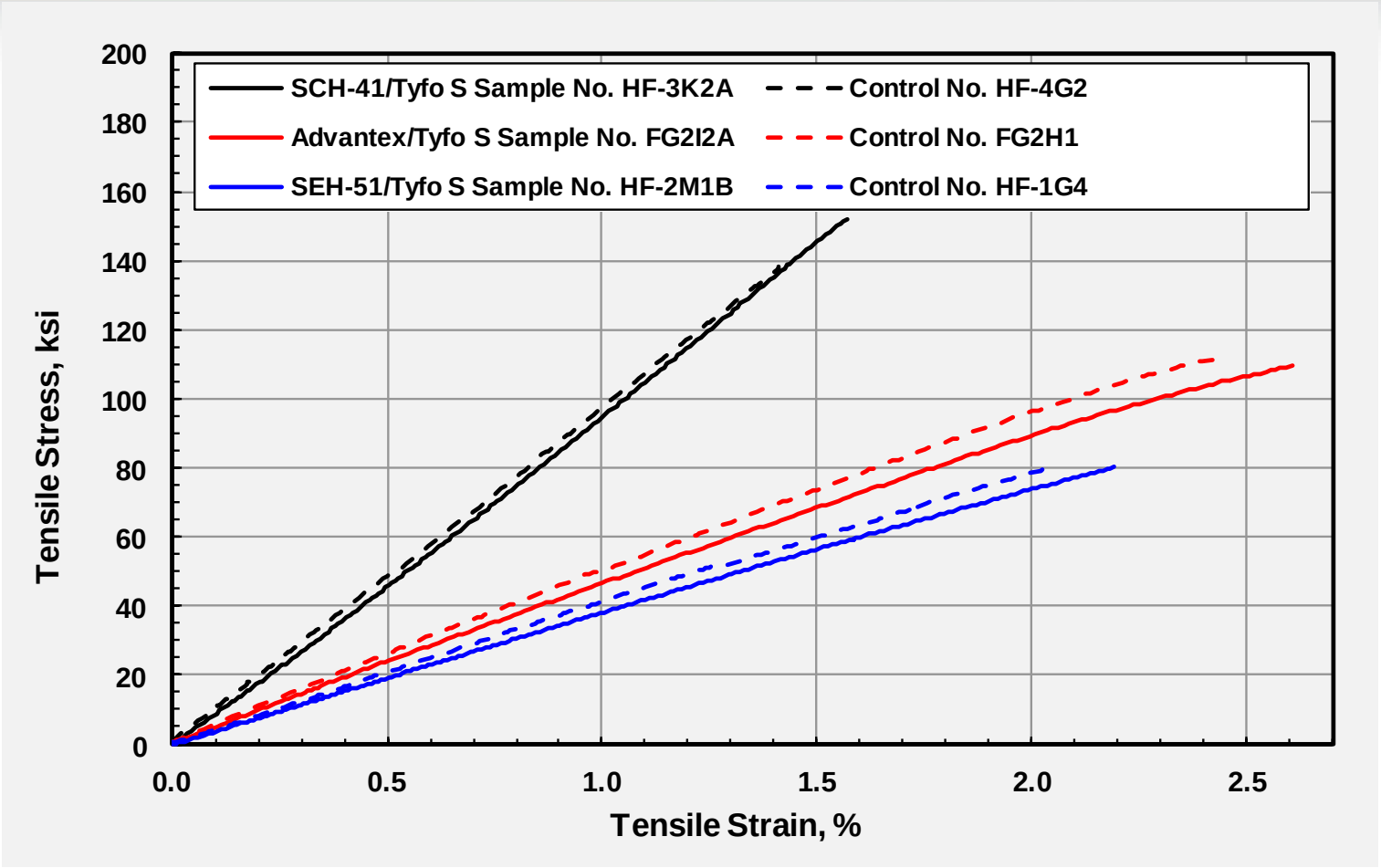
September 1999

Tyfo SEH-51 System Panels on the Yolo Causeway

October 1998

September 1999

15-Year Exposure Testing of the Tyfo Systems



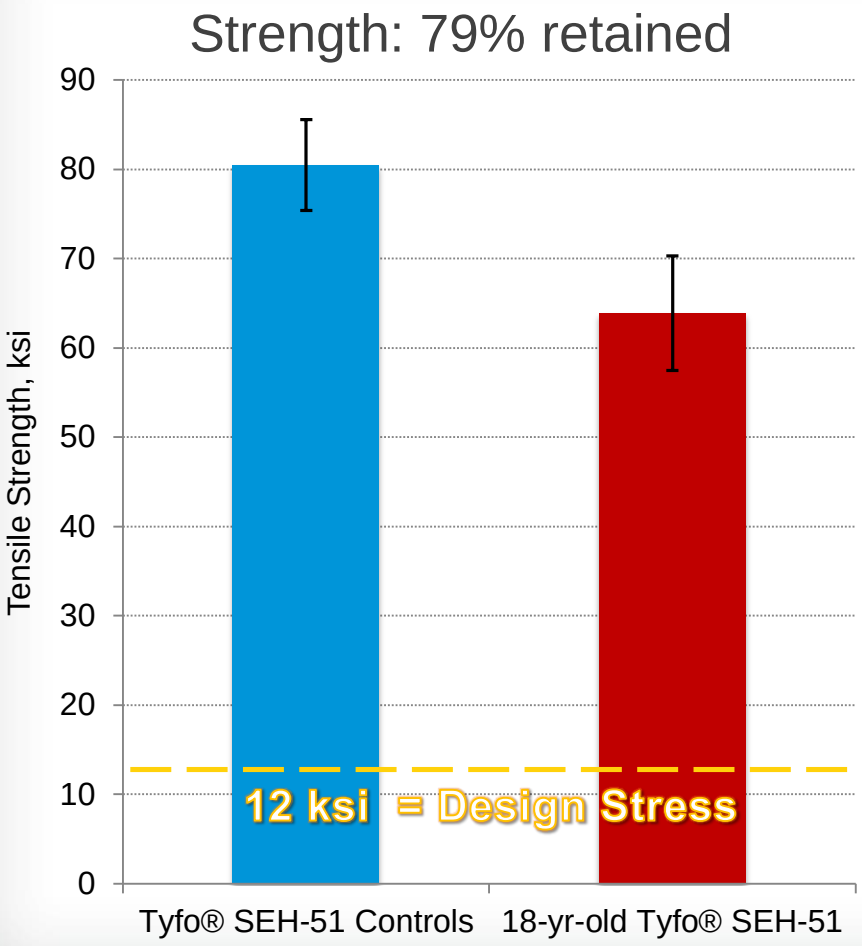
Typical stress-strain curves for Tyfo Fibrwrap composite control samples and 15–yr Yolo Causeway exposure samples.

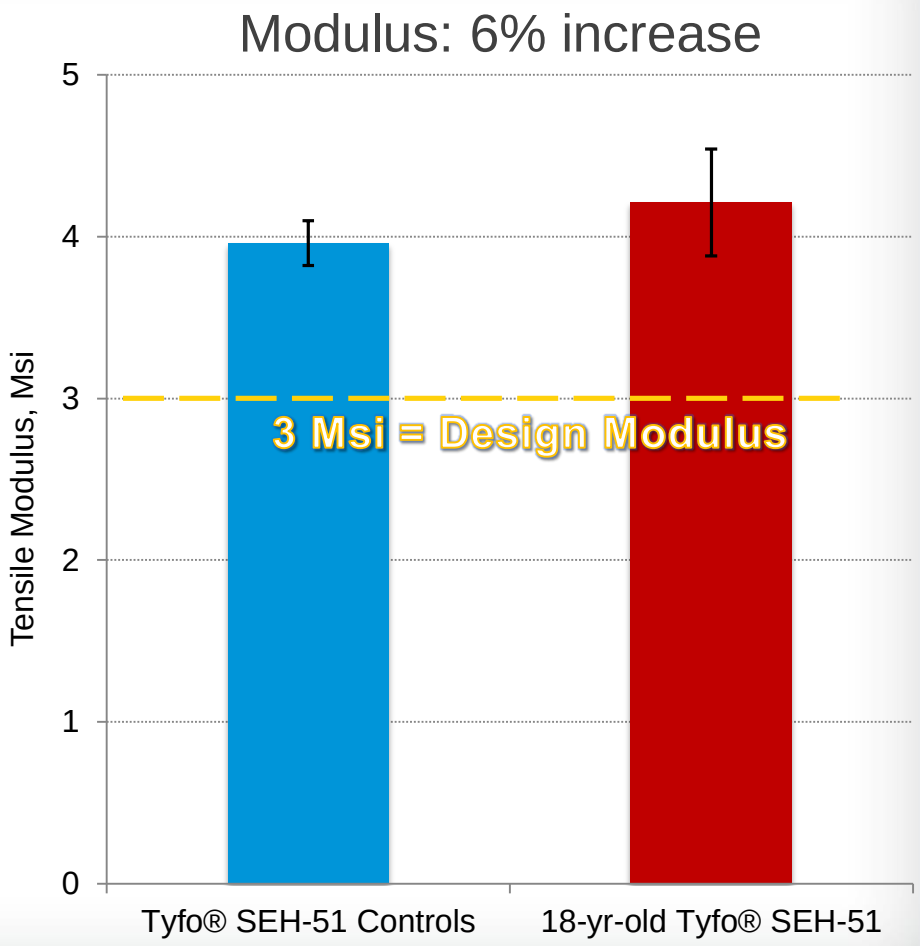
Aotea Quay Overbridge – New Zealand

In 1996, Wellington's Aotea Quay Overbridge became the first bridge in New Zealand to be seismically strengthened with FRP composite materials.

In 2013, a panel was carefully abstracted and tested at a certified laboratory

18-Year Exposure Testing of the Tyfo SEH-51 System





The Four Cornerstones of our Products and Services

Product Qualifications

Installer Qualifications

Tyfo®
FIBRWRAP® Systems

Design Qualifications

Field Quality Control