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Prequalification Requirements for FRP Systems in Civil Structures – A Review of Current Worldwide Programs

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FYFE

1988 Fyfe Company was founded

FIBERWRAP

Introduction to FRP

- *Fiber Reinforced Polymer (FRP) Composite Systems*
  - Consist of carbon, glass or aramid fiber cured in an epoxy resin
- In 1990, the first use of FRP for infrastructure rehabilitation was conducted by Caltrans as an alternative to steel jacketing.

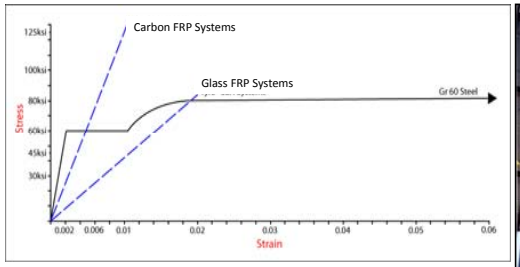


Figure: Stress – Strain Comparison

A Brief History of Testing and Development

- **1988** Product development begins
- **1990 – 1993** Research Initiated w/ **Caltrans** and **UCSD** consisting of twelve large-scale columns.
- **1993 – 1995** Series of durability and structural tests occur leading to the International Building Code Acceptance Criteria
- **1995** Intelligent Sensing for Innovative Structures (ISIS) forms in Canada.
- **1996** First full-scale column test
- Two decades of research and development combined with thousands of completed projects have led to a greater understanding of the design and use of carbon fiber wrap materials.

Introduction to FRP and Acceptance Criteria

- After the Northridge Earthquake in 1994, the ICC developed an acceptance criteria for both masonry and concrete structures.
- *The Goal of an Acceptance Criteria:*
  - To justify the use of FRP materials as an approved building material for construction purposes

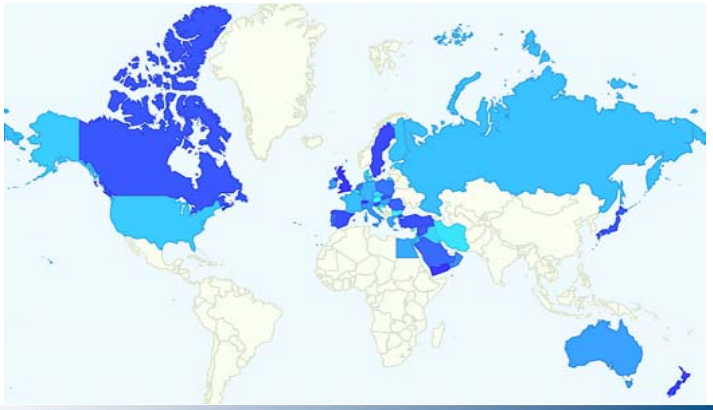
Beam:
Steel Deficiency

Chimney Stack:
Steel Deficiency

Pipe:
Rehabilitation

Bridge:
Column/Girder
Strengthening

World Map of FRP Design Guidelines and Code Approvals



Caltrans Environmental Durability Test Matrix

Environmental Durability Test	Exposure Conditions	ASTM Specifications	Exposure Duration
Water Resistance	100% Humidity at 38°C	D2247[3]	1,000, 3,000, & 10,000 hr
Saltwater Resistance	Immersion at 23°C	D1141[4], C581[5]	1,000, 3,000, & 10,000 hr
Alkali Resistance	Immersion at 23°C in $Ca(CO_3)$ Solution at pH = 9.5	C581[5]	1,000, 3,000, & 10,000 hr
Dry Heat Resistance	Circulating Air Oven at 60°C	D3045[6]	1,000 & 3,000 hr
Fuel Resistance	Immersion in Diesel Fuel at 23°C	C581[5]	4 hr
Weathering	Cycle Between UV Radiation at 60°C and Condensation at 40°C	D154[7]	4 hr per Condition, 100 Cycles (800 hr)
Freeze/Thaw Resistance	Cycle Between 100% Humidity at 38°C and Freezer at -18°C	D2247[3]	24 hr/Cycle, 20 Cycles

- From April 1996 through December 1997, The Aerospace Corporation performed environmental durability testing on Fyfe Company's Tyfo® SCH-41 carbon/epoxy composite system per Caltrans pre-qualification requirements for fiber reinforced plastics (FRP) for seismic retrofit and rehabilitation of structures.[1,2]
- The effects of the durability testing were quantified by the comparison of post-exposure tensile properties, interlaminar shear strength, and glass transition temperature to baseline values measured on control panels tested at the same time as the exposure panels.
  - One 10" x 10" x 2-ply unidirectional composite panel was subjected to each exposure duration for each environment

Building/Structural FRP Code Approvals

International Code Council (ICC): *Acceptance Criteria (AC) 125*

- ICC was established in 1994 as a non-profit organization, due to a rise in regional code development.
- *Objective of the ICC:*
  - To develop a single body of International Codes, which is both comprehensive and coordinated.
- An ***Acceptance Criteria (AC)*** is created for different structural products
  - These products are NOT part of the current international building codes
- By completing the requirements in the AC, a manufacturer obtains an ***Evaluation Service Report (ESR)*** number
  - The structural system complies with the minimum requirements and can be justified as an approved building material per the current building code

International Code Council (ICC): *Acceptance Criteria (AC) 125*

Acceptance Criteria for FRP Composite Systems

- AC 125: *"Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems"*
  - Compliant with the current IBC and UBC

Large-Scale Structural Testing	Composite Testing	Environmental/Durability Testing	
• Columns • Beam-column joints • Beams • Walls • Wall to floor joints • Slabs	• Young's Modulus • Poisson's Ratio • In-Plane Shear Modulus • Coefficient of Thermal Expansion • Glass Transition Temperature	• Exterior Exposure • Freezing and Thawing • Aging • Alkali Soil Resistance • Fire-Resistant Construction	• Interior Finish • Fuel Resistance • Adhesive Lap Strength • Bond Strength • Drinking Water Exposure

Canadian Standards Association (CSA): *S806-12*

- The CSA was established in 1919 as a non-profit organization
- CSA S806: *Design and Construction of Building Structures with Fibre-Reinforced Polymers*
  - First published in 2002, with a newest edition coming out in 2012
  - Developed to directly address the requirements for design and evaluation of FRP composite systems

Section 1 (General Design Requirements)	Section 2 (Appendices for Quality Control Testing)	
• Design of both wet lay-up, near-surface mounted, and pre-stressed FRP Systems • Mechanical Properties • Provisions for seismic design • Construction techniques and requirements • Design of fiber-reinforced concrete composite cladding	• Cross-Sectional Area • Tensile Properties • Coefficient of Thermal Expansion • Bond-to-Concrete Strength • Development Length	• Alkali Resistance • Overlap Splice Tension • Tensile Fatigue of FRP Rods • Test method for FRP Bent Bars and Stirrups • Creep of FRP Rods

Technical Report (TR) 55/57

- Created in 2000, by the Concrete Society
- *Objective of the Technical Report:*
  - Develop a design guideline for FRP strengthening
- TR 55 – *Design Guidance for Strengthening Concrete Structures using Fibre Composite Material*
  - Published in 2000
  - Includes design guidelines for strengthening structural members for flexure, shear and axial loading conditions
  - No clear guidance on installation procedures and long-term performance
- TR 57 – *Strengthening Concrete Structures using Fibre Composite Materials: Acceptance, Inspection, and Monitoring*
  - Published in 2003
  - To be used in conjunction with the TR 55

Allgemeine Bauaufsichliche Zulassung (abZ)

- Translated Means: *General Building Approval*
  - Developed by: German Institute for Building Technology (DIBt)
- *Objective of the abZ:*
  - Perform required testing on the FRP system to prove adequacy as an approved building material
  - Results will be reviewed by a committee of experts to determine if abZ approval is granted
  - Can be quite costly (up to 30,000 euros, excluding product testing costs)

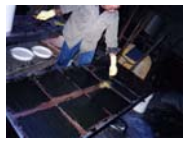
Approval Notification Document will include:	
• Description of FRP Composite Systems • Scope of Intended Applications • Specification of FRP Composite System • Design and Dimensions	• Quality Control procedures for installation • Quality Assurance procedures for care and maintenance

CodeMark (CM):
Certification of Conformity

- Established in 2010 as a joint certification program by:
  - New Zealand's Ministry of Business, Innovation, and Employment
  - Australian Building Codes Board
- *Objective of CodeMark:*
  - Designed to improve building quality and performance
  - Non-building code approved materials find acceptance through this program and comply with the current building codes
- *Requirements for FRP Systems*
  - Currently just a voluntary program
  - Adopted the requirements of the ICC AC 125
  - Third-party inspection agency verifies the testing and manufacturing meet the current building code requirements
  - Annual audit to keep the certificate valid and current

Comparison of the Different Acceptance Criteria:
Introduction

1. ***Qualification Test Plan***
   - Full/large-Scale Structural Tests
2. ***Composite Testing***
   - Testing of the Composite System
   - Environmental/Durability Testing
3. ***Quality Control / Quality Assurance***
   - Manufacturing
   - Installation
   - Long-term Inspection
4. ***Design Guidelines***



Comparison of the Different Acceptance Criteria:
Qualification Test Plan

<u>Requires Large Scale Structural Testing</u>

1. **Columns**
   - Axial, flexural and Shear tests
2. **Beam – Column Joints**
3. **Beams**
   - Flexure and Shear Tests
4. **Walls**
   - Out-of-plane & in-plane shear testing
5. **Wall to Floor Joints**
6. **Slabs**
   - Flexural Testing

Comparison of the Different Acceptance Criteria:
Composite Testing

<u>Consists of 11 different tests</u>

Physical and Mechanical Properties
Exterior Exposure
Freezing and Thawing
Aging
Alkali Soil Resistance
Fire-Resistant Construction
Interior Finish
Fuel Resistance
Adhesive Lap Strength
Bond Strength
Drinking Water Exposure

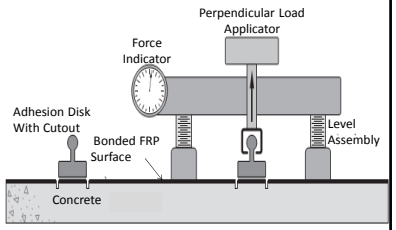


Figure: Direct Tension Pull-of Test, i.e. Bond Strength Test

Comparison of the Different Acceptance Criteria: *Composite Testing*

Physical and Mechanical Properties Test
Tests conducted only on the composite itself

- Young's Modulus
- Poisson's Ratio
- In-Plane Shear Modulus
- Coefficient of Thermal Expansion
- Glass Transition Temperature

*Note: All the Acceptance Criteria require this testing

Figure: Direct Tension Test, i.e. Young's Modulus Test

Comparison of the Different Acceptance Criteria: *Composite Testing*

All remaining testing requirements can be considered *Environmental / Durability Testing*

- Exterior Exposure
- Freezing and Thawing
- Aging
- Alkali Soil Resistance
- **Fire-Resistant Construction**
- Interior Finish
- Fuel Resistance
- Adhesive Lap Strength
- **Bond Durability**
- Drinking Water Exposure

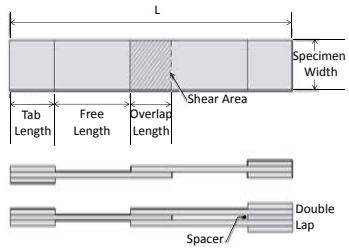


Figure: Direct Tension Pull-of Test, i.e. Adhesive Lap Strength

Corrosion Rehabilitation - Halifax

Ihiihilauakea Bridge - Historic Bridge Strengthening

Yolo Causeway – 3.2 mile elevated highway

CFRP Test Panels Exposed to the Environment

October 1998

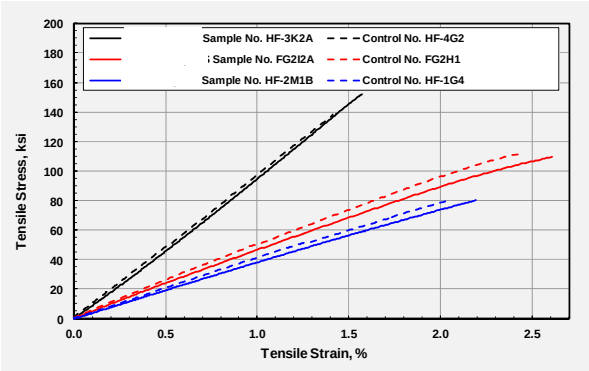
September 1999

Field Durability Study at Yolo Causeway

Sample No.	Young's Modulus, msi	Tensile Strength, ksi	Failure Strain, %
2 yr at Yolo Causeway: Panel HF-3I1			
HF-3I1A	10.0	140	1.41
HF-3I1B	9.64	140	1.46
HF-3I1C	9.15	153	1.65
HF-3I1D	10.3	139	1.34
HF-3I1E	9.92	151	1.54
HF-3I1F	9.68		
Average	9.78	145	1.48
St. Dev.	0.39	7	0.12
4 yr at Yolo Causeway: Panel HF-3K1			
HF-3K1-1	9.56	145	1.40
HF-3K1-2	9.88	145	1.38
HF-3K1-3	9.06	136	1.47
HF-3K1-4	8.91	137	1.57
HF-3K1-5	9.35	129	1.32
Average	9.35	138	1.43
St. Dev.	0.39	7	0.10

- Field durability study conducted by Aerospace for Caltrans at Yolo Causeway near Sacramento, CA
  - 10" x 6" panels for 8 different composite systems were mounted on bridge columns on October 29, 1998 for planned 10 yr field durability study
  - Included 6 composite panels from same lot of material used for laboratory durability study
    - Panel HF-3I1 removed Sept. 5, 2000 (2 yr exposure)
    - Panel HF-3K1 removed Nov. 14, 2002 (4 yr exposure)
    - Study discontinued due to insufficient funding after 2002 tests
      - » Remaining 4 panels were not removed for evaluation & should still be mounted on columns with 15 yr exposure
  - Yolo Causeway environment
    - Causeway traverses an estuary at Tule Canal that is flooded during winter months
    - Composite panels submerged approx. 2 months from mid January to early March at approx. 50°F (10°C)
    - Hot, dry summer conditions with typical nighttime temps. of 60°F (16°C) and daytime temps. of 85°F (29°C)
- Post-exposure tensile tests immediately after removal
  - Average Young's modulus & tensile strength within 1σ of baseline average for 2 yr & 4 yr exposure periods

Summary of 15-year Durability Data for Composite Systems



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

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Thank You

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