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

1988 Fyfe Company was founded.

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

- 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.

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

Figure: Stress – Strain Comparison

Bridge: Column/Girder Strengthening
Chimney Stack: Steel Deficiency
Pipe: Rehabilitation
Beam: Steel Deficiency

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World Map of FRP Design Guidelines and Code Approvals

Caltrans Environmental Durability Test Matrix

<table>
<thead>
<tr>
<th>Environmental Durability Test</th>
<th>Exposure Conditions</th>
<th>ASTM Specifications</th>
<th>Exposure Duration</th>
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<tbody>
<tr>
<td>Water Resistance</td>
<td>100% Humidity at 38°C</td>
<td>D2244[1]</td>
<td>1,000, 3,000, &amp; 10,000 hr</td>
</tr>
<tr>
<td>Saltwater Resistance</td>
<td>Immersion at 23°C</td>
<td>D1141[1], C581[1]</td>
<td>1,000, 3,000, &amp; 10,000 hr</td>
</tr>
<tr>
<td>Alkali Resistance</td>
<td>Immersion at 23°C in CaCO₃ Solution at pH = 9.5</td>
<td>C581[1]</td>
<td>1,000, 3,000, &amp; 10,000 hr</td>
</tr>
<tr>
<td>Dry Heat Resistance</td>
<td>Circulating Air Oven at 60°C</td>
<td>D3045[1]</td>
<td>1,000 &amp; 3,000 hr</td>
</tr>
<tr>
<td>Humidity at 23°C D22473</td>
<td>1,000, &amp; 10,000 hr</td>
<td>4 hr</td>
<td></td>
</tr>
<tr>
<td>Saltwater Resistance</td>
<td>Immersion in Diesel Fuel at 23°C</td>
<td>C581[1]</td>
<td>4 hr per Condition, 100 Cycles (900 hr)</td>
</tr>
<tr>
<td>Fuel Resistance</td>
<td>Immersion in Diesel Fuel at 23°C</td>
<td>C581[1]</td>
<td>4 hr per Condition, 100 Cycles (900 hr)</td>
</tr>
<tr>
<td>Alkali Resistance</td>
<td>Immersion in Diesel Fuel at 23°C</td>
<td>C581[1]</td>
<td>4 hr per Condition, 100 Cycles (900 hr)</td>
</tr>
<tr>
<td>Frost/Thaw Resistance</td>
<td>Cycle Between 100% Humidity at 38°C and Freezer at -18°C</td>
<td>D2244[1]</td>
<td>24 hr/Cycle, 20 Cycles</td>
</tr>
<tr>
<td>Weathering</td>
<td>Cycle Between UV Radiation at 60°C and Condensation at 40°C</td>
<td>D1547</td>
<td>800 hr</td>
</tr>
</tbody>
</table>

• One 10” x 10” x 2 ply unidirectional composite panel was subjected to each exposure duration for each environment.

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

  - Compliant with the current IBC and UBC

<table>
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<th>Large-Scale Structural Testing</th>
<th>Composite Testing</th>
<th>Environmental/Durability Testing</th>
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<td>Columns</td>
<td>Young’s Modulus</td>
<td>Interior Finish</td>
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<tr>
<td>Column-Beam Joints</td>
<td>Poisson’s Ratio</td>
<td>Fuel Resistance</td>
</tr>
<tr>
<td>Beams</td>
<td>In-Plane Shear Modulus</td>
<td>Adhesive Lap Strength</td>
</tr>
<tr>
<td>Walls</td>
<td>Coefficient of Thermal Expansion</td>
<td>Bond Strength</td>
</tr>
<tr>
<td>Wall to Floor Joints</td>
<td>Glass Transition Temperature</td>
<td>Drinking Water Exposure</td>
</tr>
<tr>
<td>Slabs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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

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 Bauaufsichtliche 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: Qualification Test Plan**

Requires Large Scale Structural Testing

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**

Consists of 11 different tests

**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, 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

Corrosion Rehabilitation - Halifax

Ihiliualakea Bridge - Historic Bridge Strengthening
Field Durability Study at Yolo Causeway

- Field durability study conducted by Aerospace for Caltrans at Yolo Causeway near Sacramento, CA
- "10" x 6" panels for 6 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-3K1 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 6 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. SFMP (10PC)
    - Hot, dry summer conditions with typical nighttime temps. of 60°F (16°C) and daytime temps. of 90°F (32°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

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Control No.</th>
<th>Young’s Modulus, msi</th>
<th>Tensile Strength, ksi</th>
<th>Failure Strain, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF-3K2A</td>
<td>FG2G1</td>
<td>7.4</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>HF-3K2B</td>
<td>FG2H1</td>
<td>7.6</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>HF-3K2C</td>
<td>FG2I1</td>
<td>7.8</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>HF-3K2D</td>
<td>FG2J1</td>
<td>7.9</td>
<td>0.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Sample No. HF-3K2A
- Control No. FG2G1

Sample No. HF-3K2B
- Control No. FG2H1

Sample No. HF-3K2C
- Control No. FG2I1

Sample No. HF-3K2D
- Control No. FG2J1

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