ICC-ES Evaluation Report

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DIVISION: 03 00 00—CONCRETE
Section: 03 01 00—Maintenance of Concrete

DIVISION: 04 00 00—MASONRY
Section: 04 01 20—Maintenance of Unit Masonry

REPORT HOLDER:

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EVALUATION SUBJECT:

CONCRETE AND MASONRY STRENGTHENING USING THE TYFO® FIBRWRAP® FIBER-REINFORCED COMPOSITE SYSTEMS

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2009 *International Building Code*® (IBC)
- 2009 *International Plumbing Code*® (IPC)
- 1997 *Uniform Building Code*™ (UBC)
- 1997 *Uniform Plumbing Code* (UPC)

Properties evaluated:

- Structural
- Fire propagation
- Toxicity
- Fire resistance

2.0 USES

The Tyfo® Fibrwrap Fiber-reinforced Composite Systems are used as alternatives to systems described in the IBC and UBC to strengthen concrete and masonry structural elements. The systems also may be used for weather protection, interior finish, and fire resistance.

3.0 DESCRIPTION

3.1 General:

The Tyfo® Fiberwrap systems are externally bonded fiber reinforced polymer (FRP) systems applied to normal-weight concrete and masonry substrates. The systems consist of carbon, glass, aramid and hybrid fabrics combined with resins which, in combination, create the FRP composite system.

3.2 Materials:

3.2.1 General: All materials must comply with specifications outlined in Appendix B of the Fyfe Co. quality control manual (hereinafter referred to as the QCM), revision 10, dated August 2010.

3.2.2 Fabrics: The SEH, SCH, WEB, and BC fabrics are composed of either carbon or glass fibers. Standard rolls measuring 675 square feet (62.1 m^2) for the SEH fabric, 600 square feet (55.1 m^2) for the SCH fabric, 1562 square feet (145 m^2) for the WEB fabric, or 1,200 square feet (110.4 m^2) for the BC fabric are shipped in boxes, and special roll sizes are available. Material properties vary with fiber designation.

3.2.3 Tyfo® S Epoxy Matrix: The Tyfo S epoxy matrix is an ambient cure epoxy resin mix used to bind the fibers. Components A and B of the matrix are shipped in either 5-gallon (18.9 L) buckets or 55-gallon (208 L) drums and must be mixed at either the jobsite or the facility of the approved fabricator at a volumetric ratio of 100:42 (A:B) for five minutes in a low-speed (400-600 rpm) mixer prior to application. Pot life is three to six hours at 68°F (20°C).

3.2.4 Tyfo SEH-51 (A) Composite: In the primary direction (0°), the glass fiber composite has a minimum ultimate tensile strength of 66 ksi (460 MPa), a minimum tensile modulus of 3,036 ksi (20.9 GPa), and a corresponding elongation of 1.7 to 4 percent. Layer thickness is 0.05 inch (1.30 mm).

3.2.5 Tyfo SCH Composites:

3.2.5.1 Tyfo SCH 41S(1) Composite: In the primary direction (0°), the carbon fiber composite has a minimum ultimate tensile strength of 107 ksi (745 MPa), a minimum tensile modulus of 8,900 ksi (61.5 GPa), and a corresponding elongation of 0.8 to 1.7 percent. Layer thickness is 0.04 inch (1.04 mm).

3.2.5.2 Tyfo SCH-41 Composite: In the primary direction (0°), the carbon fiber composite has a minimum ultimate tensile strength of 121 ksi (834 MPa), a minimum tensile modulus of 11,900 ksi (82 GPa), and a corresponding elongation of 0.8 to 1.7 percent. Layer thickness is 0.04 inch (1 mm).

3.2.5.3 Tyfo SCH-41 2X Composite: In the primary direction (0°), the carbon fiber composite has a minimum ultimate tensile strength of 121 ksi (834 MPa), a minimum

tensile modulus of 11,900 ksi (82 GPa), and a corresponding elongation of 0.8 to 1.7 percent. Layer thickness is 0.08 inch (2 mm).

3.2.6 WEB Composite: In both directions (0°/90°), the glass fiber composite has a minimum ultimate tensile strength of 35 ksi (247 MPa), a minimum tensile modulus of 2,240 ksi (15.4 GPa), and a corresponding elongation of 1.2 to 4 percent. Layer thickness is 0.01 inch (0.25 mm).

3.2.7 Tyfo BC Composite: In both directions (±45°), the glass fiber composite has a minimum ultimate tension strength of 32 ksi (223 MPa), a minimum tensile modulus of 2,160 ksi (14.9 GPa), and a corresponding elongation of 1.2 to 4 percent. Layer thickness is 0.034 inch (0.86 mm).

3.2.8 Tyfo FC Base Coat: The Tyfo FC base coat is a two-component epoxy-based material. Component A is packaged in 2.4-gallon (9 L) containers. Component B is packaged in 0.59-gallon (2.23 L) containers. One hundred parts of Component A must be mixed with 24.5 parts of Component B, by volume.

3.2.9 Tyfo F Top Coat: The Tyfo F top coat is a specifically formulated acrylic paint packaged in 3-gallon (11.36 L) containers.

3.2.10 Tyfo PWC: The Tyfo PWC finish coat is a two-component epoxy-based material. One hundred parts of Component A must be mixed with 40.7 parts of Component B by volume for five minutes in a low-speed (400-600 rpm) mixer. Both Component A and Component B are packaged in 5-gallon (19 L) containers.

3.2.11 Tyfo RR: Tyfo RR is an acrylic-based liquid material with natural stone, packaged in $3^1/_2$-gallon (13.2 L) containers.

3.2.12 Tyfo CR: The Tyfo CR ceramic coating is a ceramic-based material packaged in 1-gallon (3.79 L) containers.

3.2.13 Tyfo IM: The Tyfo IM mastic coating is a water-based intumescent material packaged in 5-gallon or 55-gallon (18.9 L or 206 L) containers.

3.2.14 Tyfo VG Primer: The Tyfo VG Primer is an acrylic-based primer packaged in 1-gallon (3.79) and 5-gallon (19 L) containers.

3.2.15 Tyfo VG Dashcoat: Tyfo VG Dashcoat is a cementitious spatter coat packaged in 48-pound (22 kg) bags.

3.2.16 Tyfo VG: Tyfo VG is a lightweight gypsum-based blend packaged in 40-pound (18 kg) bags.

3.2.17 Tyfo EI-R: Tyfo EI-R is an acrylic-based liquid material packaged in 3.5-gallon (13.2 L) containers.

3.2.18 Storage Recommendations: For the epoxy matrices, coatings, and fibers, water contamination and temperatures above 90°F (32°C) or below 40°F (4°C) should be avoided. Storage life must not exceed one year for the Tyfo F Tyfo VG Primer, and Tyfo EI-R, two years for the other fluid materials, and ten years for the fabric.

4.0 DESIGN AND INSTALLATION

4.1 Design:

4.1.1 General: Design of the composite system must be based on required tensile loads at designated concrete or masonry strain values. The strength design requirements for concrete or masonry must be in accordance with Chapter 19 or 21, respectively, of the IBC or UBC. The owner and registered design professional must be responsible for determining, through analysis, the strengths and demands of the structural elements to be enhanced by the Tyfo System, subject to the approval of the code official.

4.1.2 Composite Design Properties: Structural design properties for the composites are found in Appendix B of the QCM, and in the Fyfe Co. LLC Design Manual (hereinafter referred to as the DM), Revision 9, dated July 2010.

4.1.3 Design Details: Design equations described in the DM are based on test results and principles of structural analysis. Bases of design include strain compatibility, load equilibrium and limit states. All designs must follow procedures as detailed in the IBC or UBC; and in the DM. The DM also provides guidance on protecting the composite materials in areas where they are prone to impact.

4.1.4 Load Combinations: The load combinations used in design must comply with Section 1605 of the IBC or Section 1612 of the UBC. Strength reduction factors must comply with Chapter 19 (ACI 318-08) or Chapter 21 (ACI 530-08) of the IBC; or Chapter 19 or Section 2108 of the UBC.

4.1.5 Columns:

4.1.5.1 Potential Applications: The composite systems are applied to columns to enhance their ductility and their axial, flexural and shear strengths, and to provide confinement of lap splices of steel reinforcement.

4.1.5.2 Structural Design Requirements: Concrete column design must comply with the DM and with Chapter 19 (ACI 318-08) of the IBC or Sections 1907, 1909, 1910, 1911, 1912, and 1921 of the UBC. Masonry column design must comply with the DM and with Section 2108 of the UBC.

4.1.6 Beams and Slabs:

4.1.6.1 Potential Applications: The composite systems are applied to beams to enhance their ductility and their flexural and shear strengths; or to slabs to enhance flexural and in-plane shear and punching shear strengths. Slab flexural design must be limited to gravity load resistance only.

4.1.6.2 Structural Design Requirements: Concrete design must comply with the DM and with either Chapter 19 (AC 318-08) of the IBC or Sections 1907, 1909, 1910, 1911, 1912 and 1921 of the UBC. Masonry design must comply with the DM and with either Chapter 21 (ACI 530-08) of the IBC or Section 2108 of the UBC.

4.1.7 Walls and Wall-Slab Connections:

4.1.7.1 Potential Applications: The composite systems are applied to concrete walls to enhance out-of-plane flexural, in-plane flexural and shear strengths. The composite systems are applied to masonry walls to enhance out-of-plane flexural and in-plane flexural strengths.

4.1.7.2 Structural Design Requirements: Concrete wall design must comply with the DM and with either Chapter 19 (AC 318-08) of the IBC or Sections 1907, 1909, 1910, 1911, 1912, 1914 and 1921 of the UBC. Masonry design must comply with the DM and with either Chapter 21 (ACI 530-08) of the IBC or Sections 2106 and 2108 of the UBC.

4.1.8 Bond Strength: Where the bond is critical to system design, the bond strength of the system applied to a properly prepared surface must exceed the tensile strength of the substrate. Bond strength must be at least

200 psi (1378 kPa) for concrete or at least $2.5\sqrt{f'_m}$ for masonry. Testing in accordance with ASTM D4541 can be used to estimate the bond strength of bond-critical installations. The test results must exhibit failure in the concrete or masonry substrate. Sufficient bond area must be used to prevent bond failure.

4.2 Installation:

Installation must be performed by certified applicators or approved fabricators in accordance with Appendices A and B of the QCM. Installation of the system is detailed in Appendix A of the QCM.

4.2.1 Saturation: The fibers and the matrix must be combined in accordance with an established weight-and-volume ratio, using the calibrated Tyfo Saturator or manual methods.

4.2.2 Application: The saturated composite fabric must be applied to the substrate using manual (hand-applied) methods. Manual methods must be used to remove air bubbles and to ensure desired fiber orientation. Pot life of the saturated fabric is three hours at 70°F (21°C), and varies with temperature: higher temperatures result in a lesser pot life, and lower temperatures result in a longer pot life.

4.2.3 Finishing: A final protective layer of thickened Tyfo S Epoxy Matrix, described in Section 3.2.3, is applied and can be coated with one of the following:

4.2.3.1 Paint: Paints may be applied as required for weather protection and aesthetic considerations.

4.2.3.2 Flame-spread Coatings:

4.2.3.2.1 Tyfo FC and F: When applied to concrete or masonry elements to satisfy code requirements for interior finish, the use of Tyfo FC base coat and Tyfo F top coat yields a flame-spread index of 25 or less and a smoke-developed index complying with Section 803.1 of the IBC or Section 802.2 of the UBC. The composite must be limited to a maximum of six layers. Application instructions for the Tyfo FC base coat and the Tyfo F top coat are found in Appendix A of the QCM.

4.2.3.2.2 Tyfo RR: When the application is to structural elements to satisfy code requirements for interior finish, the use of Tyfo RR top coat over Tyfo SEH 51 (A) or Tyfo SCH composites yields a flame-spread index of 25 or less and a smoke-developed index complying with Section 803.1 of the IBC or Section 802.2 of the UBC. The Tyfo SEH 51 (A) composite must be limited to a maximum of six layers. Tyfo RR must be applied at a rate of 0.56 psf (2.7 kg/m^2) to a thickness ranging from 30 mils to 60 mils (0.75 mm to 1.5 mm).

4.2.3.3 Health Effects Coating: Tyfo® PWC epoxy is formulated for potable water contact and complies with Section 605 of the IPC based on ANSI/NSF 61. The material must be applied in two coats to a total dry film thickness ranging from 10 mils to 19 mils (0.025 mm to 0.5 mm). Surfaces include concrete, masonry, steel or cured composites. All surfaces must be clean, dry and free of contaminants. Concrete, masonry and steel surfaces must be prepared by water-blasting, sandblasting or shot-blasting. Composite surfaces must be prepared by hand-sanding the surface to remove the gloss of the cured composite and then cleaning with water to remove residues. The cure interval between coats must be 24 hours. Final curing must be 24 hours at 40°F to 72°F (4°C to 22°C). The Tyfo® PWC coating must not be used where an interior finish complying with Chapter 8 of the IBC or UBC is required.

4.2.3.4 Fire-resistance-rated Assemblies:

4.2.3.4.1 Spray-applied Fire-resistive Material: The use of the Tyfo Advanced Fire Protection (AFP) System yields up to a four-hour fire-resistance rating in accordance with ASTM E119. The AFP system consists of four components applied over the composite system and concrete in accordance with the QCM procedures.

The Tyfo AFP System must be applied to square, normal-weight concrete columns measuring 16 inches (406 mm) by 16 inches (406 mm), with a minimum 28-day compressive strength of 6,000 psi (41.3 MPa). Grade 60 reinforcement must consist of four No. 8 vertical bars and four No. 3 horizontal hoops spaced 16 inches (406 mm) on center. The concrete surface must be primed with Tyfo S Primer. Tyfo SEH fabric must be saturated with Tyfo S epoxy matrix with minimum 0.14 lb/ft^2 (0.68 kg/m^2) saturation. Three layers of Tyfo SEH fabric must be wrapped around the column exterior.

The Tyfo AFP System must be applied to concrete tee beams measuring 12 inches web width, 10 inches web depth, 6 inches flange thickness, and 4 feet flange width, with a minimum 28-day compressive strength of 6,000 psi (41.3 MPa), and reinforced with No. 6 bottom longitudinal reinforcing steel in the web. Flange (slab) reinforcement must be No. 3 at 6 inches (152 mm) on center, top and bottom in both directions. Stirrups must be No. 3 at 6 inches (152 mm) on center Tyfo SCH saturated with Tyfo S with minimum 0.27 lb/ft^2 (1.3 kg/m^2) saturation. The saturated Tyfo SCH fabric must be applied to the bottom web of the concrete tee beam. Two layers of Tyfo SEH saturated with Tyfo S are used with minimum 0.17 lb/ft^2 (0.83 kg/m^2) saturation as U-wrap at the ends of the beam to anchor Tyfo SCH mesh.

Tyfo VG Primer is spray-applied to the substrate at 0.008 lb/ft^2 (0.04 kg/m^2). Before the primer is dry, Tyfo® VG Dash Coat is spray-applied as a skim coat over the primer at 0.17 lb/ft^2 (0.83 kg/m^2). Tyfo® VG must be mixed with water and spray-applied in one or more coats to a minimum average thickness of $1^3/_8$ inches for beam-slab assemblies and $1^5/_8$ inches for columns (vertical elements). Tyfo® EI-R must be applied as a topcoat over Tyfo® VG at 0.46 lb/ft^2 (2.2 kg/m^2).

Other assembly configurations are beyond the scope of this report.

4.2.3.4.2 Tyfo 4HFL Column Wrap System: The use of the Tyfo 4HFL System yields up to a four-hour rating in accordance with ASTM E119. The application of the Tyfo 4HFL System is to columns. The system consists of three components applied over the composite system in accordance with the QCM procedures.

The Tyfo 4HFL System must be applied to square, normal-weight concrete columns measuring 16 inches (406 mm) by 16 inches, with a minimum 28-day compressive strength of 6,000 psi (41.3 MPa). Grade 60 reinforcement consists of four No. 8 vertical bars and four No. 3 horizontal hoops spaced 16 inches (406 mm) on center. The system consists of three layers of SEH composite saturated with Tyfo S epoxy matrix applied in a manner such that the last layer overlaps the first layer by 6 inches (152 mm). Horizontal joints must be butted. One layer of Tyfo Web Composite follows, pressed into the wet SEH composite and allowed to cure.

The Fibrwrap System is coated with Tyfo CR mastic coating in two or more coats at a minimum dry thickness of $^3/_{32}$ inch (2.4 mm), and is allowed to cure for 24 hours at 72°F (22°C) or four hours at 150°F (65°C). Tyfo FC base coat must be applied over Tyfo CR in two coats at an

application rate of 0.893 lb/ft^3 (14.3 kg/m^3) to achieve a minimum thickness of $^1/_{32}$ inch. Tyfo FC must be allowed to cure as described in the quality control manual. The column is finished with Tyfo IM spray-applied in three coats at a rate of 0.4 oz/ft^2 (127 mL/m^2) per coat to a $^1/_{16}$-inch (1.6 mm) minimum thickness. This column, as described in this section, must be designed as a restricted load-bearing column having a design load capacity no greater than 60 percent of the calculated design load with the FRP composite reinforcement in order to qualify as a four-hour fire-resistance-rated assembly.

Other assembly configurations are beyond the scope of this report.

4.2.4 Cure Time Prior to Loading: The Tyfo composites must be allowed 48 hours of cure time at an average temperature of 70°F (21.1°C) prior to the loading of the structural member.

4.3 Special Inspection:

Special inspection must comply with the applicable requirements in Sections 1704 through Section 1707 of the IBC or Section 1701 of the UBC. Special inspection during the installation of the system must be in accordance with the ICC-ES Acceptance Criteria for Inspection and Verification of Concrete and Unreinforced Masonry Strengthening Using Fiber-reinforced Polymer (FRP) Composite Systems (AC178), dated June 2003. Inspection must also comply with Sections 1704 to 1709 of the IBC or Section 1701 of the UBC, and with Appendix A of the QCM.

5.0 CONDITIONS OF USE

The Tyfo Fibrwrap Fiber-reinforced Composite Systems described in this report comply with, or are suitable alternatives to what is specified in, those codes listed in Section 1.0 of this report, subject to the following conditions:

5.1 Design and installation must be in accordance with this report, the Quality Documentation, Revision 10, dated December 2011, the Design Manual, Revision 9, dated July 2010, and the IBC or UBC.

5.2 Copies of the Fyfe Co. Quality Documentation, Revision 10, dated December 2011, and the Design Manual, Revision 9, dated July 2010, must be submitted to the code official with each project using the systems.

5.3 Complete construction documents, including plans and calculations verifying compliance with this report, must be submitted to the code official for each project at the time of permit application. The construction documents must be prepared and sealed by a registered design professional where required by the statutes of the jurisdiction in which the project is to be constructed.

5.4 Except as described in Section 4.2.3.4, fire-resistance ratings of the concrete or masonry fire-resistance-rated assembly must comply with Chapter 7 of the IBC or UBC and are not reduced by application of the Tyfo system. The structural load-carrying capacities of fire-resistance-rated assemblies shall be based on the design of the concrete or masonry without the Tyfo system in accordance with the IBC or UBC.

5.5 Special inspection for jobsite application of the Tyfo systems must be provided in accordance with Section 4.3 of this report.

5.6 Application of the systems to concrete or masonry members at a fabricator's facility must be by an approved fabricator complying with Section 1704.2.2 of the IBC or Section 1701.7 of the UBC, or at a jobsite with continuous special inspections in accordance with Section 1704.4 of the IBC or Sections 1701.5.1 and 1701.5.3 of the UBC.

5.7 Tyfo materials must be manufactured by Fyfe Co. LLC in San Diego, California, under a quality control program with inspections by UL LLC (AA-668).

6.0 EVIDENCE SUBMITTED

Data in accordance with the ICC-ES Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-reinforced, Composite Systems (AC125), dated February 2010, including reports of fire-resistance tests and surface burning tests.

7.0 IDENTIFICATION

Tyfo system components must be labeled, in accordance with the QCM, with the Fyfe Co. LLC name and address, product name, expiration date, evaluation report number (ESR-2103) and the name of the inspection agency (UL LLC).