FYFE Co. LLC
Tyfo® Fibrwrap® Systems

MD8571/72/73

APR 22 2008

FROM: FYFE CO. LLC
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SUBJECT: Test Program: GFRP Retrofitted CMU Brick Walls for Enhanced Performance under Uniform Pressures

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1.0 Purpose

This test program provides guidance for the building of test specimens, materials, test procedures, FRP composite reinforcement schedules, time line of actions, and references.

2.0 Goal of Test Program

To demonstrate that fiber-reinforced polymer composites can be used to increase the flexural strength of existing double-wythe, 4-inch solid core concrete masonry unit walls.

3.0 Materials

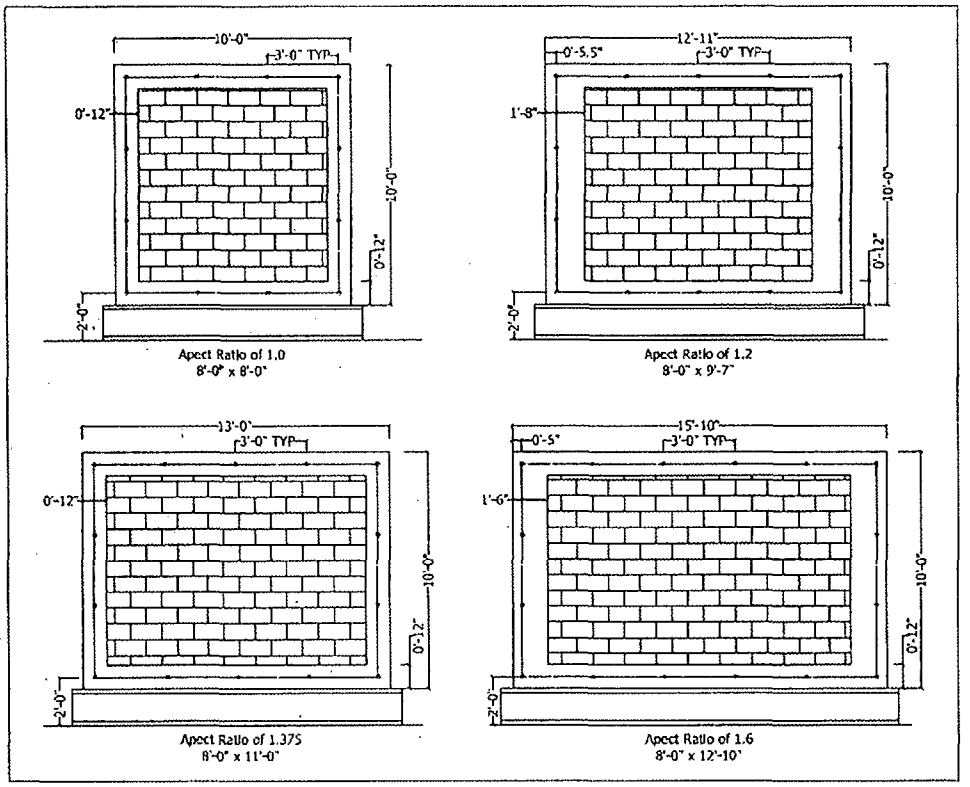
- Tyfo® S Epoxy – is a two-component epoxy matrix material for bonding applications. Tyfo® S epoxy is clear to yellow in color and can be thickened with an inert filler for finishing.
- Tyfo® WP – is an epoxy formulation developed to provide a primer/membrane undercoat specifically for use in wet, damp, or moist substrates.
- Tyfo® WS Epoxy - is a two-component, hi-build, 100% solids epoxy formulation developed for bonding applications. It can be used as a final protective coating or as a fill-and-level undercoat over which the Tyfo® Fibrwrap System may be applied. This material may be used either as a surface coating or a primer material.
- Tyfo® SEH-51A – is a custom weave, uni-directional glass fabric used in the Tyfo® Fibrwrap System. The glass material is orientated in the 0° direction with a non-structural support yellow glass cross fiber at 90°.
- Cab-O-Sil Fumed Silica (inert filler)
- Solid lightweight concrete brick 3 5/8" x 7 5/8" x 2 1/4" per ASTM C55-06
- Type S Mortar per ASTM C270-07 (consists of Type S masonry cement per ASTM C91-01, natural sand per ASTM C144-04, and potable water)
- Number 8 wire reinforcing and 9-gage transverse wires per ASTM A82-07
- Conventional A 615 Gr. 60 Steel reinforcement rebar #3 and #6
- 5000 psi concrete

4.0 Test Program

4.1 Test Specimens

4.1.1 Construction of Wall Specimens – Fourteen wall specimens will be constructed out of representative 4-inch solid-core concrete masonry units. The walls will be 2-wythe thick and framed by reinforced concrete beam elements. One control specimen will be constructed with an aspect ratio of 1.0. The remaining thirteen walls, earmarked for FRP strengthening, will be constructed with respective aspect ratios of 1.0, 1.2, 1.4, and 1.6, three specimens of each and an additional wall constructed at the largest aspect ratio of 1.6. See Figure 4.1.

4.1.2 Masonry Prisms – Three prism specimens, 2-wythe thick, two brick lengths wide and eight courses high, will be constructed and tested per ASTM C1314-07. In addition to the newly constructed prism specimens, three additional specimens will be taken directly from the walls at the Owner's facility and tested per ASTM C1314-07.



4.1 Test Specimens

4.2 Structural Testing

The specimens will be loaded with uniform pressure using an air bag to apply increasing static pressure at increments of 0.6 psi up to failure. Each wall specimen will be monitored for both strain and deflection at appropriate locations. The proposed test setup is shown below in Figure 4.2 Setup.

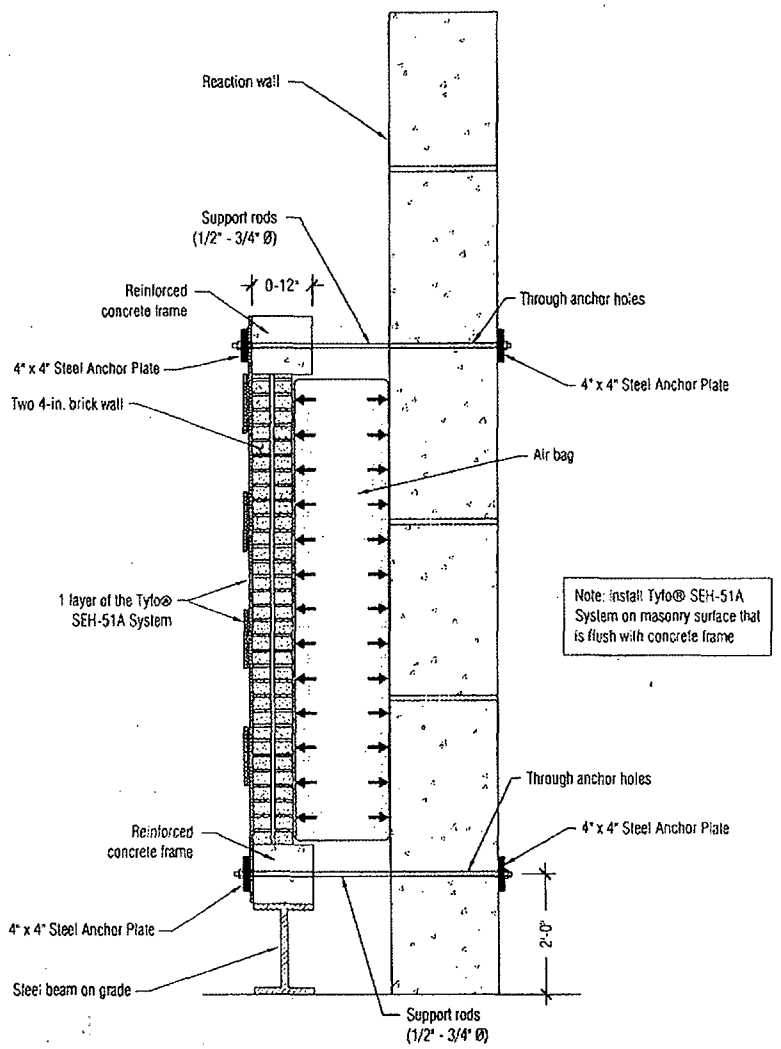


Figure 4.2 Test Setup

5.0 FRP Strengthening Schedules

Strengthening schedules for each wall specimen will be based on the design methodology described in Attachment 5 to Owner specification OSS-0308.00-00-0006, "Specification for the Design of the Natural Phenomenon Barrier System." Strengthening schedules for wall specimens will be shown on shop drawings. Actual test results will be compared to calculated wall capacities, and any necessary adjustments to the design methodology will be made before each new test series.

6.0 Execution of Work

6.1 Installation Procedures for Tyfo® Composites

Installation of the Fyfe Co. LLC Tyfo® Composites will follow the project specification Section 03930 and be supported by the Fyfe Co. LLC Quality Control Manual for the Tyfo® Fibrwrap® System, February 2007, Revision 8.0.

6.2 Laboratory Material Testing

6.2.1 FRP Coupon Testing - Record the lot number of fabric and resin used and location of installation. A "sample batch" shall consist of two 12" x 12" samples of cured composite. A minimum of two

sample batches shall be made daily. The two sample batches will be taken at appropriate times during the day so as to ensure the maximum material deviance in the components of the composite. Testing laboratory shall pre-condition samples at 140° F for 48 hours before testing. Samples shall be tested per ASTM D3039. The 12" x 12" panel shall have 5 coupons, ¾" x 9", removed and tested for their material properties in the longitudinal (primary fiber) direction. Tests shall conform to ASTM procedures and manufacturer's published testing methods. Only pre-qualified testing laboratories shall be used.

6.2.2 Masonry Prism Testing – Per ASTM C1314-07.

6.3 Items of Caution

6.3.1 Moving of Wall Specimens – The specimens will be lifted by means of Meadow-Burke inserts embedded in the top of the reinforced concrete frame.

6.3.2 Cold Weather Conditions – All Tyfo® materials will be stored in a dry environment with temperatures above 40 degrees Fahrenheit. During the masonry construction, special attention should be made to ensure temperatures do not drop below 40 degrees Fahrenheit. If necessary, measures should be taken using heaters and tarps to prevent the mortar from freezing prior to final set.

6.3.3 Mechanical Damage – All parties involved in the construction and/or testing should be careful not to cause visible or non-visible mechanical damage.

6.3.4 Appropriate Cure Times - The concrete frames should be allowed to reach a minimum compressive strength of 4000 psi before being tilted-up for masonry infill. Masonry should cure for a minimum of 28-days prior to structural testing. The masonry work should cure a minimum of 7 days before the application of the Tyfo® Composites. The Tyfo® Composites should be allowed to cure a minimum of 10-days prior to structural testing.

6.4 Test Procedures

6.4.1 Applied Pressure - The pressure will be applied using an air bag. The applied pressure will be measured using a calibrated pressure transducer with a range of 0-15 psi. Furthermore, at the Testing Facility's discretion, strain gages may be installed on the steel rods supporting the wall to measure the strain in the rods, and hence determine the force in each rod. Determining the forces in the steel rods will enable verifying the total applied load versus the applied pressure.

6.4.2 Application of Load - Test wall specimens will be subjected to cycles of loading and unloading according to the proposed loading protocol shown below. Load pressure will be applied in load-control mode and <u>not</u> displacement-control mode. The proposed loading protocol is based on ASTM E 72 (Standard Test Methods of Conducting Strength of Panels for Building Construction) and ACI 437.1R-07 (Load Tests of Concrete, Structures: Methods, Magnitude, Protocols, and Acceptance Criteria). The loading increment will be 0.6 psi up to a discernable failure mode. After 1.2 psi, the loading increment will be 0.6 psi as shown in the figure below. At each loading step, the pressure load level will be maintained constant for 5 minutes as specified by ASTM E 72. At the minimum pressure level (0.6 psi) the pressure will be maintained for 1 minute.

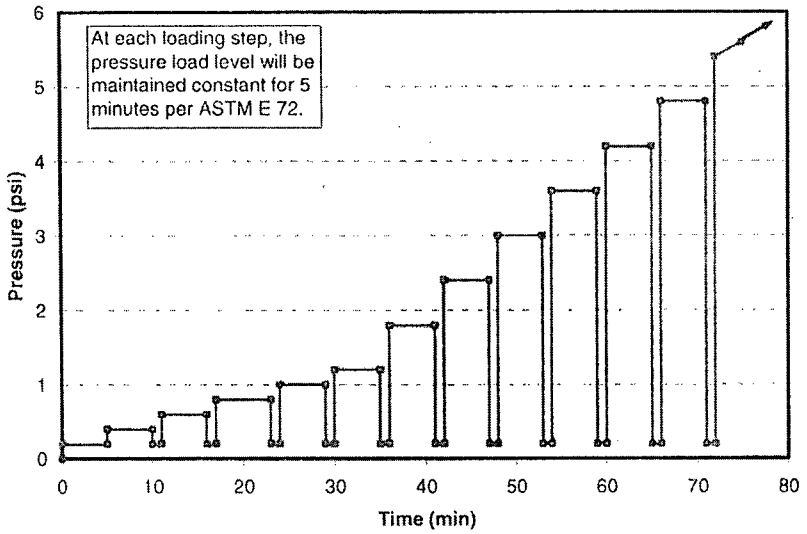


Figure 6.4.3 Loading Protocol

6.4.3 Instrumentation – Eight string potentiometers will be used to measure the deflections of the brick wall as well as the concrete frame. Deflection will be measured at the horizontal and vertical centerlines as shown in the Figure 6.4.6 below. Strain gages will be installed on the FRP sheets in the direction of the fibers to measure the strains developed. Locations of strain gages will confirmed after testing the un-strengthened (control) specimen (C1-1.0).

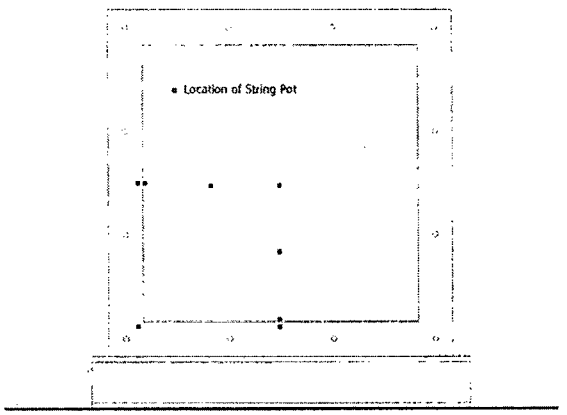


Figure 6.4.6 Location of Strings Pots

6.4.4 Data Acquisition - Data will include measurements of applied pressure, deflection, and strains in FRP sheets. In addition, digital photographs will be continuously taken to reflect the progress of cracking.

6.4.5 Analysis of Mode of Failure – The mode of failure of each wall specimen will be described as one of the following or as some combination as below.

- Flexural-shear across masonry units
- Sliding-shear of bedding joint near the support
- Flexural: Masonry: crushing of masonry in compression
- Fiber: rupture of laminate in tension
- Fiber: Debonding of laminate from substrate

7.0 Test Parameters

7.1 Anchors

Anchors have been omitted in Series 1. If testing shows anchors are necessary to prevent premature failure, a retrofit scheme will be designed using Tyfo® Fiber Composite Anchors.

7.2 GFRP Composite Reinforcement Ratio

The amount of GFRP Composite is the chief parameter that will be varied throughout the test program. This composite reinforcement ratio can be adjusted by the number of layers, width and spacing of strips. The GFRP reinforcement ratio for each test specimen will be determined jointly by the Owner, Fyfe Co, and NC State.

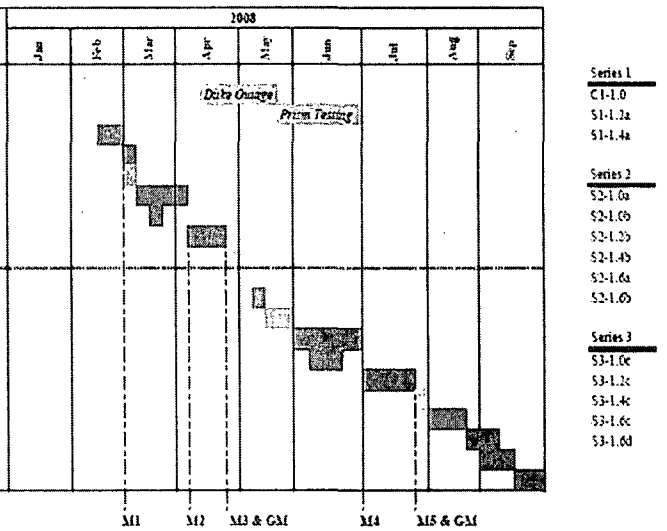
8.0 Test Schedule

#RD636 - 6318

Fyfe Co. LLC RD # 636 Test Program Schedule
GFRP Retrofitted CMU Brick Walls for Enhanced Performance Under Uniform Pressures

2/22/2008

Milestone Task	Duration (weeks)	End Date
Kickoff Meeting with NC State (Raleigh, NC)	-	2/4/2008
Overview Meeting with Fitor (Seneca, SC)	-	2/15/2008
Initial Wall Construction		
Series 1 RC Frame Construction	1	2/29/2008
Series 1 RC Frames Cure	1	3/7/2008
Masonry Construction of Series 1	1	3/7/2008
Masonry Cures	4	4/4/2008
Fibrwrap® Series 1 (Composite cures for 10-days)	2	3/21/2008
Test Series 1	3	4/25/2008
Review Test Data from Series 1	2	5/9/2008
Complete Wall Construction		
Construct RC Frames for Series 2 & 3	1	5/16/2008
Masonry Construction of Series 2 & 3	2	5/30/2008
Masonry Cures	4	6/27/2008
Fibrwrap® Series 2 & 3	2	6/20/2008
Test Series 2 (6-walls)	4	7/25/2008
Review Test Data Series 2	1	7/31/2008
Test Series 3 (5-walls)	3	8/22/2008
Data compiled, reduced, reported from NC State	2	9/5/2008
Design and test program review	2	9/12/2008
Fyfe Co compiles final report	2	9/26/2008



*Prism construction not shown, but all prism tests are earmarked for testing during the month of June during the cure time of Series 2 and 3.
** Estimated time for wall test = 1.5 walls / week

Schedule Legend

Planning / Meeting
Reinforced Concrete Frame Construction
Masonry Construction
Cure time
Fibrwrap
Testing
Review and Compiling of Test Report

Milestones & Suggested Project Team Meeting Dates

M1 Start of masonry construction with Duke representative on site supervising masonry aspects.
M2 Initial test on Series 1.
M3 Test Series 1 complete and suggested project team meeting in Raleigh, NC.
M4 Start of testing for Series 2.
M5 Test Series 2 complete and suggested project team meeting in Raleigh, NC.

Specimen Identification

S3 - 1.2b

- Letter designates successive tests in a particular aspect ratio
- Specimen aspect ratio
- Series identifier
- S - specimen with FRP reinforcement, C - control specimen no FRP reinforcement

Fyfe Co. LLC

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9.0 References

- Fyfe Co. LLC Quality Control Manual for the Tyfo® Fibrwrap® System, February 2007, Revision 8.0
- International Code Council (ICC) Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems, AC 125
- Fyfe Co. LLC ICC ESR-2103
- Underwriters Laboratories Inc, Inspection Report Type R Service, dated 8/16/2007
- Specification for FRP Strengthening System, Section 03930.