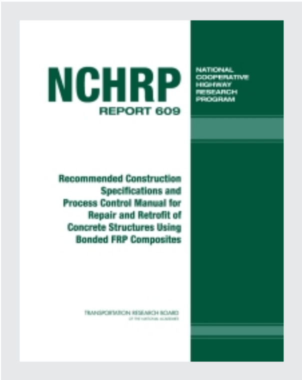

Recommended Construction Specifications and Process Control Manual for Repair and Retrofit of Concrete Structures Using Bonded FRP Composites

DETAILS

61 pages | | PAPERBACK
ISBN 978-0-309-42062-4 | DOI 10.17226/23116

AUTHORS

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 609

Recommended Construction Specifications and Process Control Manual for Repair and Retrofit of Concrete Structures Using Bonded FRP Composites

Amir Mirmiran
FLORIDA INTERNATIONAL UNIVERSITY
Miami, FL

Mohsen Shahawy
SDR ENGINEERING CONSULTANTS, INC.
Tallahassee, FL

Antonio Nanni
CO-FORCE AMERICA, INC.
Miami, FL

Vistasp Karbhari
UNIVERSITY OF CALIFORNIA
San Diego, CA

AND

Baris Yalim
Ahmet Serhat Kalayci
FLORIDA INTERNATIONAL UNIVERSITY
Miami, FL

Subject Areas
Bridges, Other Structures, and Hydraulics and Hydrology

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2008
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NCHRP REPORT 609

Project 10-59B
ISSN 0077-5614
ISBN: 978-0-309-09928-8
Library of Congress Control Number 2008901883

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 10-59B by the Structures and Construction Laboratory in the Department of Civil and Environmental Engineering at the Florida International University. SDR Engineering Consultants, Inc.; Professor Antonio Nanni of the Co-Force America, Inc. and the University of Miami; and Professor Vistasp Karbhari of the University of California, San Diego were the sub-consultants to the Florida International University for this project.

Amir Mirmiran, Professor and Chair of the Department of Civil and Environmental Engineering and Director of Structures and Construction Laboratory at Florida International University, was the Principal Investigator. The other contributors to this document are Mohsen Shahawy, President, SDR Engineering Consultants, Inc.; Antonio Nanni, President, Co-Force America, Inc., and Professor and Chair of the Department of Civil, Architectural, and Environmental Engineering at the University of Miami; and Vistasp Karbhari, Professor of Structural Engineering at the University of California, San Diego.

Doctoral students who worked on this project were Mr. Baris Yalim and Mr. Ahmet Serhat Kalayci in the Department of Civil and Environmental Engineering at the Florida International University.

FOREWORD

By Amir N. Hanna
Staff Officer
Transportation Research Board

This report presents recommended construction specifications to facilitate highway agencies' use of bonded fiber-reinforced polymer (FRP) composites for the repair and retrofit of concrete structures. These specifications cover the construction of FRP systems used as externally bonded or near surface-mounted reinforcement to enhance axial, shear, or flexural strength of a concrete member. These specifications are supplemented by a construction process control manual that provides a program for assuring a consistent and uniform control of quality and regulatory requirements. The material contained in this report will be of immediate interest to engineers, inspectors, contractors, suppliers, and others involved in the repair and retrofit of concrete structures using FRP composites.

The long-term performance of repair and retrofit of concrete structures using bonded FRP composites is very sensitive to the process by which the FRP material is stored, handled, mixed, applied (including preparation of the underlying concrete surface), and cured. A finished FRP composite is characterized by both its constituent materials and the process by which those materials are formed into a composite; not solely by the constituent materials as is commonly done. Achieving the as-designed properties of FRP composites requires the adherence to specific process control. However, because of the difficulty in quantifying the relationship between the long-term performance of FRP applications and the construction process, there has been no rational basis for developing construction specifications that will assure the expected performance. Thus, research was needed to investigate such a relationship and develop recommended construction specifications and a construction process control manual for bonded FRP repair and retrofit of concrete structures to assure performance as designed. NCHRP Project 10-59 and subsequently Projects 10-59A and 10-59B were conducted to address this need. Project 10-59A produced preliminary construction specifications and a construction process control manual that were further examined and enhanced in NCHRP Project 10-59B.

Under NCHRP Project 10-59B, "Construction Specifications for Bonded Repair and Retrofit of Concrete Structures Using FRP Composites," Florida International University conducted an experimental program to investigate the long-term performance of concrete structures that were repaired or retrofitted using bonded FRP composites. The program covered different forms of surface preparation and FRP defects and the range of environmental conditions encountered during installation. Results of this investigation were then used (a) to recommend enhanced construction specifications and a process control manual for such repair or retrofit of concrete structures, and (b) to identify threshold values for surface preparation, FRP defects, and environmental conditions during installation. Use of the recommended specifications, manual, and threshold values will help assure performance as designed.

The recommended specifications and process manual will be particularly useful to highway agencies because their use will help assure quality and long service life of the repaired or retrofitted structure and reduce maintenance requirements. Their adoption as *AASHTO Construction Specifications and Process Manual for Repair and Retrofit of Concrete Structures Using Bonded FRP Composites* will further encourage their use and is, therefore, recommended.

The agency research report that provides details of the experimental investigation and the research findings supporting the recommended construction guidelines, construction process manual, and threshold values is not published herein. The report is available on TRB website at *http://trb.org/news/blurb_detail.asp?id=8718*.

CONTENTS

CHAPTER 1

Introduction

1.1 Problem Statement

The repair and retrofit of concrete structures with bonded fiber-reinforced polymer (FRP) systems has progressively increased over the last 2 decades. Light weight, ease of installation, minimal labor costs and site constraints, high strength-to-weight and stiffness-to-weight ratios, and durability have all made FRP repair systems economically viable alternatives to traditional repair systems and materials. However, the long-term performance of FRP systems is affected not only by their constituent materials, but also by the processes used during construction. Moreover, because the relationships between the long-term performance of FRP systems and their construction processes are not easy to quantify, generally accepted construction specifications and process control procedures for FRP repair systems are not readily available.

NCHRP Project 10-59 developed a Recommended Construction Specifications and Process Control Manual, presented in *NCHRP Report 514* (Mirmiran et al. 2004). However, the study identified a number of issues that required further research, among which, thresholds for surface preparation, criticality of FRP defects, and criticality of environmental conditions during installation were considered most important. Thresholds for surface preparation, FRP defects, and environmental conditions during installation needed to be more strongly tied to an experimental database that would support the construction specifications and process control manual in those areas. The need for training and technology transfer was also noted. NCHRP Project 10-59B was therefore conducted to address these issues.

1.2 Research Objective

The objective of this research was to develop a rational and experimental database to support revisions to the construction specifications and process control manual presented in *NCHRP Report 514* (Mirmiran et al. 2004), in regards to thresholds for surface preparation, FRP defects, and environmental conditions during installation.

1.3 Research Approach

The research conducted in NCHRP Project 10-59 is described in *NCHRP Report 514* (Mirmiran et al. 2004). The report included recommended construction specifications and a Process Control manual. NCHRP Project 10-59B included the following primary tasks:

1. Identify thresholds for surface roughness, surface out-of-flatness, surface voids and bug holes, surface cracks and near-surface mounted (NSM) groove size tolerance that may affect long-term performance of FRP repair systems, if not corrected.

2. Identify criticality of FRP defects and the type and size of any unacceptable defects that may affect the long-term performance of FRP repair systems, if not treated.
3. Identify thresholds for the environmental conditions during the application of the FRP repair system (e.g., temperature, humidity, and the presence of moisture on the surface to be bonded).
4. Revise the recommended construction specifications and process control manual presented in *NCHRP Report 514* (Mirmiran et al. 2004), based on findings of this research.
5. Prepare a report on the findings of this research, including revised construction specifications and a process control manual.

1.4 Report Organization

This report consists of three chapters and three attachments. This introductory chapter describes the problem statement, defines the research objectives, and outlines the approach taken in this study. Chapter 2 provides the summary of findings of this study. Conclusions and recommendations for future research are presented in Chapter 3. Attachment A presents the revised construction specifications for repair and retrofit of concrete structures using bonded FRP composites, and Attachment B includes the revised process control manual. Attachment C contains detailed information on research program description and findings. Attachment C is not published herein; it is available on the TRB website at http://trb.org/news/blurb_details.asp?id=8718.

CHAPTER 2

Findings

This study addressed several issues for construction of FRP repair systems: irregularities in concrete surface (roughness, out-of-flatness, voids, and cracks); groove size tolerance for NSM reinforcement; FRP defects; and environmental conditions during installation. A total of 109 specimens were tested. This chapter provides a brief summary of the research program and findings (for details, see Attachment C available on the TRB website).

1. **Surface Roughness:** Most FRP design and construction guidelines recommend surface preparation of concrete substrate to enhance its bond with FRP. The ACI 440.2R-02 (2002) and the recommended specifications in *NCHRP Report 514* (Mirmiran et al. 2004) both refer to the recommendations by ICRI/ACI (1999) and ACI 546R-96 (1996) for surface profiling of bond-critical applications. The ACI 440.2R-02 (2002) suggests abrasive or water blasting techniques for surface preparation to a minimum concrete surface profile CSP 3, as defined by ICRI/ACI (1999). *NCHRP Report 514* (Mirmiran et al. 2004) does not specify any CSP number for repair using bonded FRP composites.

   The objective of this part of the study was to specify possible thresholds of concrete surface roughness for FRP systems. The study included testing of 26 beams and 10 double shear bond specimens. Test parameters included surface roughness level, number of U-strap anchorage systems, and type of FRP system (wet lay-up or pre-cured).

   The tests showed that surface roughness did not have a significant effect on the performance of FRP systems. Beams with higher number of U-straps failed by rupture, while less anchorage resulted in failure by FRP debonding. Although the smoothest concrete surface profile in this study (CSP 1), as defined by ICRI/ACI (1999), appeared to provide adequate surface roughness for both wet lay-up and pre-cured FRP systems; this study recommends CSP 2–3 as a conservative measure.
2. **Surface Out-of-Flatness:** Defined as unevenness or depression over a given length, surface out-of-flatness has a strong influence on the bond behavior and the performance of FRP systems. *NCHRP Report 514* (Mirmiran et al. 2004) recommends filling any depression deeper than ⅛ in. (3.2 mm) over a length of 12 in. (305 mm). The ACI 440.2R-02 (2002) did not address this issue.

   The objective of this part of the study was to specify possible thresholds of concrete surface out-of-flatness for FRP systems. The study included testing of 16 beams. Test parameters included surface unevenness level and type (peak or valley), and type of FRP system (wet lay-up or pre-cured).

   The tests showed that peaks on concrete surface, in the range studied here, did not have a significant effect on the performance of FRP systems. However, valleys or depressions deeper than $\frac{1}{16}$ in. (1.6 mm) over a length of 12 in. (305 mm) could reduce the strength of FRP systems, and hence were suggested as a threshold for surface out-of-flatness.
3. **Surface Voids:** Voids and bug holes on concrete surface, if not attended to, may lead to early delamination failure by reducing contact surface area and the bond between FRP and concrete.

NCHRP Report 514 (Mirmiran et al. 2004) recommends filling any void with a diameter larger than ½ in. (12.7 mm) or depth greater than ⅛ in. (3.2 mm).

The objective of this part of the study was to specify possible thresholds of concrete surface voids for FRP systems. The study included testing of 20 beams. Test parameters included surface void depth and diameter, and type of FRP system (wet lay-up or pre-cured).

Tests showed that void depths of up to ¼ in. (6.4 mm) did not have a significant effect on the performance of FRP systems. Threshold of ½ in. (12.7 mm) for void diameter, as recommended by *NCHRP Report 514* (Mirmiran et al. 2004) appear to be conservative based on test data. However, for durability purposes, the study does not recommend changing the specified threshold.

4. **Surface Cracks:** Cracks in concrete surface not only affect the bond between FRP and concrete, but also affect how concrete transfers the forces to the FRP system. *NCHRP Report 514* (Mirmiran et al. 2004) and ACI 440.2R-02 (2002) both recommend epoxy injection of cracks wider than 0.01 in. (0.25 mm).

   The objective of this part of the study was to specify possible thresholds of concrete surface cracks that could be left untreated for FRP systems. The study included testing of 20 beams. Cracks were simulated using thin saw-cut grooves in the surface of concrete. Test parameters included surface cut width and frequency (i.e., spacing), and type of FRP system (wet lay-up or pre-cured).

   Tests showed that surface cuts of up to ⅛ in. (3.2 mm) did not have a significant effect on the performance of FRP systems. Test data confirmed similar findings by Delaney and Karbhari (2006) who studied the effect of surface cracks by preloading FRP-strengthened specimens. The *NCHRP Report 514* (Mirmiran et al. 2004) recommendation for crack injection may be considered too conservative.

5. **NSM Groove Size:** Retrofit of reinforced concrete members using NSM FRP reinforcement is a viable alternative to conventional techniques and externally bonded FRP systems. *NCHRP Report 514* (Mirmiran et al. 2004) has not recommended tolerances for NSM grooves.

   The objective of this part of the study was to specify groove size tolerance for NSM FRP systems. The study included testing of 12 beams. Test parameters included groove size, and type of NSM FRP system (strip or bar).

   Tests showed that a ± ⅛ in. (3.2 mm) tolerance in the groove size of 9/16 in. (14 mm) may be acceptable for both NSM strips and bars. Tests also showed the dominant failure mode to change from epoxy splitting to concrete splitting, as the grove size is increased.

6. **FRP Defects:** Defects in FRP systems can range from voids and disbonds at the bond line or within the FRP to fiber misalignment and inconsistency of primer or resin. *NCHRP Report 514* (Mirmiran et al. 2004) recommends FRP defects larger than ¼ in. (6.4 mm) but smaller than 1¼ in. (32 mm) in diameter to be filled with epoxy injection, those larger than 1¼ in. (32 mm) but smaller than 6 in. (152 mm) in diameter to be patched, and those larger than 6 in. (152 mm) in diameter to be replaced.

   The objective of this part of the study was to further investigate the practical aspects of these tolerances and whether existing guidelines could be improved. A comprehensive study to investigate the effects of FRP defects on the overall performance of the system was carried out by Delaney and Karbhari (2006).

   Test results of Delaney and Karbhari (2006) suggest that present guidelines on criticality of FRP defects, such as *NCHRP Report 514* (Mirmiran et al. 2004) and ACI 440.2R-02 (2002) are conservative. Disbonds smaller than 2 in. (50 mm) had little or no effect on the performance of FRP systems. Even very large unbonded sections with dimensions up to 9.8 × 5.9 in. (250 × 150 mm) or diameters reaching the entire 5.9 in. (150 mm) width of the section showed only local effects, and had limited measurable influence on the overall performance of FRP systems. However, for durability purposes, the study does not recommend changing the specified thresholds.

7. **Environmental Conditions during Installation:** Long-term performance of FRP systems may be affected by the environmental conditions during installation. *NCHRP Report 514* (Mirmiran et al. 2004) recommends avoiding cold, frozen, damp, or wet surfaces; applying FRP only in the temperature range of 50°–95°F (10°–35°C); and limiting moisture level on all contact surfaces to less than 10%.

   The objective of this part of the study was to further investigate the practical aspects of these tolerances and whether existing guidelines could be improved. Review of the relevant information in the literature suggests the following environmental conditions during installation for optimum bond performance: surface moisture less than 4.3%; relative humidity between 65% and 82%; and temperature between 50° and 90°F (10° and 32°C).

CHAPTER 3

Conclusions

Based on test results from this research, and review of relevant literature, the following conclusions can be made for each of the studied topics:

1. **Surface Roughness:**
   a) Surface roughness did not significantly influence the performance of wet lay-up FRP systems (with or without adequate anchorage) and whether FRP systems fail from debonding or rupture.
   b) The three groups of wet lay-up specimens exhibited different modes of failure. Specimens with no straps failed by debonding of FRP sheet, specimens with four and seven straps failed in the same way after the straps were ruptured, and specimens with 11 straps or full continuous straps failed by rupture of FRP sheets.
   c) The higher level of anchorage did not affect the strength as much as it affected the ductility for the retrofitted beams.
   d) The smoothest concrete surface profile in this study (CSP 1) as defined by ICRI/ACI (1999) appears to provide an adequate surface roughness level for both wet lay-up and pre-cured FRP systems. However this study recommends CSP 2–3 to be conservative.
2. **Surface Flatness**:
   a) An out-of-flatness on the concrete surface in the form of ⅛ in. (3.2 mm) over a 12-in. (305-mm) length had a significant effect on the overall performance of the retrofitted beams. However, behavior of beams with $1/16$-in. (1.6-mm) valleys was quite similar to that of control (level) specimens. Therefore, $1/16$ in. (1.6 mm) over a 12 in. (305 mm) length seems to be an appropriate threshold for valleys and depressions.
   b) Peaks on concrete surface were found to be less critical than valleys of the same size. *NCHRP Report 514* (Mirmiran et al. 2004) does not recommend threshold values for these peaks, and the results from this study do not support any changes.
   c) Bond reduction factor, which is a function of maximum strain in FRP at debonding, decreases with the increase of surface curvature or rise-to-chord ratio.
   d) All surface flatness specimens (wet lay-up or pre-cured) failed by debonding of FRP, regardless of the type and extent of the out-of-flatness. FRP debonding in specimens with valleys was initiated at both ends of the valleys and propagated to both ends of the specimens.
3. **Surface Voids:**
   a) All specimens with surface voids and four straps failed by debonding of FRP that initiated at the mid-span and propagated toward the supports until one of the U-straps ruptured. Use of higher anchorage (i.e., 11 straps) increased load capacity and led to failure by FRP rupture.
   b) Load-deflection and load-strain responses of all specimens were quite similar, indicating that surface voids in the range studied do not significantly affect the overall behavior of FRP system, although there was a slight reduction in load capacity with an increased void diameter.

c) Using response surfaces with the design of experiment analysis, void depth appears to have no direct effect on the response of FRP system. The recommended ½ in. (12.7 mm) as a threshold for void diameter, as specified by *NCHRP Report 514* (Mirmiran et al. 2004) appears conservative.

4. **Surface Cuts:**
   a) Cracking in concrete surface simulated as surface cuts did not appear to significantly affect the response of FRP retrofitted beams. Moreover, stress concentrations due to preloading cracks do not significantly affect the overall performance of FRP-retrofitted beams. Based on tests of 20 specimens, it appears that recommendation of *NCHRP Report 514* (Mirmiran et al. 2004) for injection of cracks wider than 0.01 in. (0.25 mm) is conservative. A threshold value of 1⁄32 in. (0.8 mm) is recommended instead, primarily for durability concerns rather than structural reasons. The *NCHRP Report 514* (Mirmiran et al. 2004) does not recommend a threshold for crack spacing. This study showed the crack spacing of 1.5 in. (38.1 mm) to be an appropriate threshold for crack injection, if crack width is between 0.01 in. (0.25 mm) and 1⁄32 in. (0.8 mm).
   b) FRP debonding was observed in all wet lay-up and pre-cured specimens except for when number of U-straps was significantly increased. Debonding first occurred at the mid-span and then propagated towards the supports. Failure occurred after the U-straps ruptured. An additional number of U-straps provided sufficient anchorage for the FRP system to prevent premature debonding.
5. **NSM Groove Size**
   a) A tolerance of ± 1⁄8 in. (3.2 mm) in the groove size of 9⁄16 in. (14 mm) seems to have no significant effect on the performance of FRP systems with NSM strips or bars.
   b) For both NSM strips and bars, the dominant failure mode changes from epoxy splitting to concrete splitting as the groove size is increased.
6. **FRP Defects:**
   a) The guidelines on the effects of FRP defects contained in the *NCHRP Report 514* (Mirmiran et al. 2004) and the ACI 440.2R-02 (2002) are conservative. Disbonds and cracking influence the bond performance only at the local level and do not significantly affect the overall structural response of the system. However, recommendations of *NCHRP Report 514* (Mirmiran et al. 2004) are maintained for durability purposes.
   b) In general, disbonds located in the high moment regions are slightly more critical than those located within the shear span.
   c) Disbond locations, whether at the interface between the FRP layers, or within the adhesive, or at both locations should be treated equally, as they all result in very similar performance characteristics.
7. **Environmental Conditions during Installation:**
   a) Surface moisture, when measured by moisture-meter, should be limited to 4.3% to provide satisfactory bond performance.
   b) Relative humidity should be within 52% and 65% to provide satisfactory bond performance.
   c) Temperature should be within the range of 50° and 90°F (10° and 32°C) to avoid high viscosity of saturant and primer at low temperatures and rapid set of saturants at high temperatures.

The above conclusions have been incorporated into the Recommended Construction Specifications and Process Control Manual, as presented in Attachments A and B, respectively.

Finally, it should be noted that the long-term behavior of FRP defects (due to improper surface preparation, FRP application, or environmental conditions during installation) under sustained loads, fatigue loads, aging, or severe environmental exposure has not been investigated in this study. Research in this area is needed to validate the findings and recommendations of this research.

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ATTACHMENT A

Recommended Construction Specifications

The proposed Construction Specifications are the recommendations of NCHRP Project 10-59B staff at Florida International University. These specifications have not been approved by NCHRP or any AASHTO committee or formally accepted for the AASHTO specifications.

Contents

Specifications

1 General

This Specifications is intended for use in the construction of repair and retrofit of concrete structures using bonded fiber-reinforced polymer (FRP) composites. This Specifications does not include design aspects of FRP system, and the extent and limitations of the repair and retrofit of an existing concrete structure.

1.1 Scope

This Specifications covers construction of FRP systems used as externally bonded or near-surface mounted (NSM) reinforcement to enhance axial, shear, or flexural strength or ductility of a concrete member, such as column, beam, slab or wall.

1.2 Definitions

The following terms used in this Specifications are primarily taken from ACI 440.2R-02 with some changes:

Batch—A quantity of material formed during the same field installation in one continuous process, and having identical characteristics throughout.

Bi-Directional Laminate—Reinforced polymer laminate with fibers oriented in two different directions in its plane.

Binder—Resin constituent that holds together the other constituents of an FRP composite.

Bond-Critical Applications—Applications of FRP systems for strengthening structures that rely on bond to the concrete substrate. Examples are flexural and shear strengthening of beams and slabs.

Catalyst—A substance that initiates a chemical reaction and enables it to proceed under milder conditions than otherwise required and which does not, itself, alter or enter into the reaction. See hardener.

Composite—A combination of two or more materials differing in form or composition on a macro-scale. The constituents retain their identities; they do not dissolve or merge completely into one another, although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another. (See Composite FRP.)

Composite FRP—A polymer matrix, either thermosetting or thermoplastic, reinforced with a fiber or other material with a sufficient aspect ratio (length to thickness) to provide a discernible reinforcing function in one or more directions. (See Composite.)

Contact-Critical Applications—Applications of FRP systems that rely on intimate contact between concrete substrate

Commentary

C1 General

FRP systems may be used to increase live load capacity of a structure, repair members that are damaged by impact or corrosion, reduce stresses in the internal steel reinforcement, or increase ductility in seismic retrofit. For design issues, consult with relevant guidelines such as ACI 440.2R-02.

C1.1 Scope

FRP system may include externally bonded sheets, strips, plates, and shells; and near-surface mounted FRP bars and strips that are bonded inside a groove cut into the surface of concrete.

C1.2 Definitions

The definitions of the terms given herein are for consistent application of this Specifications, and may not always correspond to the ordinary usage of the term. For a glossary of the most commonly used terms related to concrete construction and FRP systems, consult with ACI 116R-00, ACI 440R-96, and ACI 440.2R-02.

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and FRP system to function as intended. An example is confinement of columns for seismic retrofit. In this Specifications, contact-critical applications are treated the same as bond-critical applications. (See Bond-critical applications.)

Creep Rupture—Failure of FRP system resulting from its gradual, time dependent reduction of capacity due to sustained loading.

Cure—The process of causing irreversible changes in the properties of a thermosetting resin by chemical reaction. Cure is typically accomplished by addition of curing agents or initiators, with or without heat and pressure. Full cure is the point at which a resin reaches its specified properties. Resin is undercured if its specified properties have not been reached.

Cure Time—The time necessary to cure a thermosetting resin system, thermoset based composite or prepreg at a given temperature.

Curing Agent—A catalytic or reactive agent that, when added to resin, causes polymerization. Also called hardener.

Debonding—A separation at the interface between substrate and the reinforcing layer.

Delamination—Separation of the layers of the FRP laminate from each other.

Development Length—The bonded distance required for transfer of stresses from concrete to the FRP to develop tensile capacity of FRP.

Durability—The ability of a material to resist cracking, oxidation, chemical degradation, delamination, wear, or the effects of foreign object damage for a specified period of time, under the appropriate load conditions and specified environmental conditions.

Epoxy—A polymerizable thermosetting polymer containing one or more epoxide groups, cured by reaction with phenols, anhydrides, polyfunctional amines, carboxylic acids, or mercaptans. An important matrix resin in FRP; also used as structural adhesive.

Fabric—Arrangement of fibers held together in two or three dimensions. It may be woven, nonwoven, knitted or stitched. Fabric architecture is the specific description of the fibers, their directions and construction.

Fiber—A general term used to refer to filamentary materials. The smallest unit of a fibrous material. Often, fiber is used synonymously with filament.

Fiber Content—The amount of fiber present in a composite, usually expressed as volume fraction or mass fraction of the composite.

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Fiber Fly—Short filaments that break off dry fiber tows or yarns during handling and become air borne, classified as nuisance dust.

Fiber Reinforced Polymer (FRP) System—Composite material consisting of a polymer matrix reinforced with cloth, mat, strands, or any other fiber form. (See Composite.)

Filament—(See Fiber.)

Filler—A relatively inert substance added to a resin to alter its properties or to lower cost or density. Also used to term particulate additives. Also called extenders.

Fire Retardant—Chemicals used to reduce the tendency of resin to burn. They can be added to the resin or coated on the surface of the FRP.

Flow—The movement of uncured resin under pressure or gravity loads.

Glass Transition Temperature (T_g)—The approximate midpoint of the temperature range over which a transition in material response from elastic to viscoelastic takes place [*ASM 2001*].

Hardener—Substance added to thermosetting resin to cause polymerization. Usually applies to epoxy resins.

Impregnation—The process of saturating the interstices of a reinforcement or substrate with a resin.

Inhibitor—A substance that retards a chemical reaction, such as ultraviolet degradation. Also used to prolong shelf life of certain resins.

Initiator—Chemicals, most commonly peroxides, used to initiate the curing process for unsaturated polyester and vinyl ester resins. See Catalyst.

Laminate—One or more layers or plies of fiber, boded together in a cured resin matrix.

Lay-Up—The process of placing the FRP reinforcing material in position for installation.

Lot—A quantity of material manufactured during the same plant production in one continuous process, and having identical characteristics throughout. In this Specifications, Batch is used interchangeably. See Batch.

Mat—A fibrous material for reinforced polymer consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric), or long random filaments loosely held together with a binder.

Matrix—The essentially homogeneous resin or polymer material in which the fiber system of a composite is embedded.

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Micro-cracking—Cracks formed in composites when stresses locally exceed the strength of the matrix.

MSDS—Material Safety Data Sheet.

Near-Surface Mounted (NSM)—Alternative repair system, where an FRP bar or strip is inserted and anchored into a precut groove.

Pin Holes—A small cavity, typically less than 0.06 in. (1.5 mm) diameter that penetrates the surface of a cured composite part.

Pitch—Petroleum or coal tar precursor base used to make carbon fiber.

Ply—A single layer of fabric or mat.

Polyester—A thermosetting polymer synthesized by the condensation reaction of certain acids with alcohols, and subsequently cured by additional polymerization initiated by free radical generation. Polyesters are used as binders for resin mortars and concretes, fiber laminates, and adhesives. Commonly referred to as "unsaturated polyester."

Polymer—A compound formed by the reaction of simple molecules, which permit their combination to proceed to high molecular weights under suitable conditions.

Polyurethane—A thermosetting resin prepared by the reaction of disocyanates with polyols, polyamides, alkyd polymers, and polyether polymers.

Postcure—Additional elevated-temperature cure to increase the level of polymer cross linking; final properties of the laminate or polymer are enhanced.

Pot Life—Time that a catalyzed resin retains a viscosity low enough to be used in processing. Also called working life.

Prepreg—A fiber or fiber sheet material containing resin whose reaction has progressed to the stage where consistency is tacky. Multiple plies of prepreg are typically cured with applied heat and pressure. Also preimpregnated fiber or sheet.

Pultrusion—A continuous process that combines pulling and extrusion for manufacturing composites that typically have a constant cross-sectional shape. The process consists of pulling a fiber material through a resin bath and then through a heated shaping die, where the resin is cured.

Resin—A component of a polymeric system that requires a catalyst or hardener to polymerize or cure for use in composites. Resin often refers to the mixed polymer component or matrix of the FRP.

Resin Content—The amount of resin in a laminate expressed as either a percentage of total mass or total volume.

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Roving—A number of yarns, strands, tows, or ends of fibers collected into a parallel bundle with little or no twist.

Shelf Life—The length of time a material, substance, product, or reagent can be stored under specified environmental conditions and continue to meet all applicable specifications or remain suitable for its intended function. Also called storage life.

Structural Adhesive—A resinous bonding agent used for transferring required loads between adherents.

Substrate—The original concrete and any cementitious repair materials used to repair or replace the original concrete. It can consist entirely of original concrete, entirely of repair materials or of a combination of the two. The FRP is installed on the surface of the substrate.

Thermoplastic—A non-cross-linked polymer capable of being repeatedly softened by an increase of temperature and hardened by a decrease in temperature. Examples are nylon, polypropylene, and polystyrene.

Thermoset—A cross-linked polymer which cannot be softened and reformed by an increase in temperature. Cross-linking is an irreversible process; thermosets cannot be returned to a molten state. Examples are epoxy, phenolic, and vinyl ester.

Tow—An untwisted bundle of continuous filaments.

Unidirectional Laminate—A reinforced polymer laminate in which substantially all of the fibers are oriented in the same direction.

Vinyl Ester—A polymerizable thermosetting resin containing vinyl and ester components, cured by additional polymerization initiated by free-radical generation. Vinyl esters are used as binders for fiber laminates and adhesives.

Viscosity—The property of resistance to flow exhibited within the body of a material, expressed in centipoises. A higher viscosity has higher resistance to flow.

Volatiles—Materials such as water and solvents in a resin formulation that are capable of being driven off as vapor.

Wet Lay-Up—A method of making a laminate system by applying the resin system as a liquid, when the fabric or mat is put in place.

Wet-Out—The process of coating or impregnating roving, yarn, or fabric in which all voids between the strands and filaments are filled with resin. It is also the condition at which this state is achieved.

Wetting Agent—A substance capable of lowering surface tension of liquids, facilitating the wetting of solids surfaces and permitting the penetration of liquids into the capillaries.

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Witness Panel—A small FRP panel, manufactured on site under conditions similar to the actual construction. The panel may be later tested to determine mechanical and physical properties to confirm the expected properties for the full FRP structure.

1.3 References

The following standards or documents are referred to in this Specifications:

ACI—*American Concrete Institute*
- 116R-00: Cement and Concrete Terminology.
- 117-90: Specifications for Tolerances for Concrete Construction and Materials, and Commentary.
- 224.1R-93: Causes, Evaluation, and Repair of Cracks in Concrete Structures.
- 224R-01: Control of Cracking in Concrete Structures.
- 440R-96: State-of-the-Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structures.
- 440.2R-02: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening of Concrete Structures.
- 503R-93: Use of Epoxy Compounds with Concrete.
- 503.4-92: Standard Specification for Repairing Concrete with Epoxy Mortars.
- 503.5R-92: Guide for the Use of Polymer Adhesives in Concrete.
- 503.6R-97: Guide for the Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concrete.
- 546R-96: Concrete Repair Guide.

ASTM—*American Society for Testing and Materials*
- D3039: Test Method for Tensile Properties of Polymer Matrix Composite Materials.
- D3418: Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry.
- D4541: Test Method for Pull-off Strength of Coatings Using Portable Adhesion Tester.
- D5687: Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation.

ICBO—*International Conference of Building Officials*
- AC125: Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) Composite Systems.
- AC178: Acceptance Criteria for Inspection and Verification of Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) Composite Systems.

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C1.3 References

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ICRI—*International Concrete Repair Institute*

No. 03730: Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion.

No. 03732: Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays.

No. 03733: Guide for Selecting and Specifying Materials for Repairs of Concrete Surfaces.

1.4 Tolerances

Tolerances recommended by the manufacturer shall be followed, unless more stringent requirements are specified in this Specifications or in the Contract Documents. In case of any conflict or appearance of any conflict, the Engineer shall provide clarification before proceeding.

1.5 Site Considerations

The Contractor shall provide necessary pathways, scaffoldings and other means of access to the general project site and to the specific repair area for the personnel, equipment and materials. All obstructions such as pipes, conduits and wiring shall be removed at the expense of the Contractor, upon approval of the Engineer and after making records for subsequent re-installation by the Contractor at the completion of the project. Plants, fences and other obstructions that prevent access for repair shall be removed, and upon approval of the Engineer, re-installed or disposed of according to Section 3.4, at the expense of the Contractor.

1.6 Fire Considerations

Fire is a life safety issue with the design of FRP systems. Most FRP systems are assumed to be lost completely in a fire due to their low temperature resistance.

2 Submittals

The Contractor shall submit the following documents for Engineer's approval before starting the work.

2.1 Working Drawings

Working (shop) drawings shall include the type of FRP system, repair locations, relevant dimensions of the system and the work plan including the necessary preparations of the existing structure. The drawings must be accompanied by the design calculations, the MSDS and the manufacturer's system data sheet

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C1.4 Tolerances

Adherence to proper tolerances is necessary to produce acceptable work. It is important to avoid accumulating tolerances. The Owner may accept the manufacturer tolerances, if appropriate test data is shown that warrants the change based on the unique characteristics of a particular system.

C1.5 Site Considerations

FRP systems can generally be installed in most locations with very limited access and minimal equipment. In most applications, the impact of FRP system on the existing utilities is minimal.

C1.6 Fire Considerations

Fire resistance of FRP system may be improved by adding fire retardants to the resin or by coating on the surface of the FRP. Other methods of fire protection may also be used.

C2 Submittals

C2.1 Working Drawings

The necessary information for each FRP system may be different. Shop drawings for wet lay-ups may include, for example, fiber orientation, nominal thickness, aerial weight of dry fabric, number of layers, fiber volume or weight fraction, locations and lengths of lap splices, end details, and anchoring.

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identifying mechanical, physical and chemical properties of all components of the FRP system; application guide, including the installation and maintenance procedures; and time schedule for various steps in the repair process. The installation procedure must clearly identify the environmental and substrate conditions that may affect the application and curing of the FRP system.

2.2 Quality Control/Quality Assurance Plan

The Contractor shall be responsible for the quality control of all materials and processes in the project. The quality control and quality assurance (QC/QA) plan must be approved by the Owner or its representative. It shall include specific procedures for personnel safety, tracking and inspection of all FRP components prior to installation, inspection of all prepared surfaces prior to FRP application, inspection of the work in progress to assure conformity with specifications, quality assurance samples, inspection of all completed work including necessary tests for approval, repair of any defective work, and clean-up. Any part of the work that fails to comply with the requirements of the Contract Documents shall be rejected by the Engineer, and shall be remedied, or removed and replaced by the Contractor at its own expense to be in full compliance with the Contract Documents.

2.3 Qualifications

Manufacturer/Supplier must be pre-qualified by the Owner or its representative for each of its FRP systems after providing the following necessary information:

1) System data sheets and MSDS for all components of the FRP system;
2) Minimum of 5 years of documented experience or 25 documented similar field applications with acceptable reference letters from respective owners;
3) Minimum of 50 test data sets (total) from an independent agency approved by the Owner on mechanical properties, aging and environmental durability of the system; and
4) Comprehensive hands on training program for each FRP system to qualify Contractors/Applicators.

Contractor/Applicator must be pre-qualified by the Owner or its representative for each FRP system after providing the following necessary information:

1) Minimum of 3 years of documented experience or 15 documented similar field applications with acceptable reference letters from respective Owners; and

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Shop drawings for near-surface mounted FRP may include, for example, locations and sizes of grooves and bars or strips. Shop drawings may also include necessary corner radii and surface conditions of the existing structure. The system data sheets may also include, for example, mix ratio, pot life, temperature-cure time data, and gel time at proposed cure temperature, and acceptable humidity and temperature range for mixing and applying the resin.

C2.2 Quality Control/Quality Assurance Plan

The quality control/quality assurance program should be comprehensive and cover all aspects of the FRP system. Quality assurance is achieved through a set of inspections and applicable tests to document the acceptability of the installation. Details of the plan in terms of inspection, testing, and record keeping may be developed to match the size and complexity of the project. Additional information regarding the necessary elements of the quality control/quality assurance plan is included in the Process Control Manual that accompanies this document. The manual ensures that the specifications are followed, and provides guidance and specific checklists for quality assurance by the Owner or its representative.

C2.3 Qualifications

Qualification of Manufacturer/Supplier for each of its FRP systems assures acceptability of the system, as well as competence of the Manufacturer/Supplier to provide it. The Owner or its representative may also require the Manufacturer/Supplier to provide a specified number of samples of the components and the complete FRP system for in-house or independent testing prior to qualification. The Owner may accept the total experience of the key personnel on similar field applications. For specific items on system data sheets, refer to Section C2.1. Test data sets may follow appropriate protocols such as those developed by HITEC [*Reynaud et al. 1999*, *CERF 2001*]. The training program by the Manufacturer/Supplier should provide hands on experience with surface preparation and installation of the same FRP system for which the certificate is issued.

Qualification of Contractor/Applicator for each FRP system assures competence of the Contractor/Applicator for surface preparation and application of a particular FRP system through evidence of appropriate training and related past experience. The Owner may accept the total experience of the

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2) Certificate of completed training from Manufacturer/Supplier for at least one field representative who will be present on site throughout the project.

3 Storage, Handling and Disposal

3.1 Storage

3.1.1 Storage Requirements

All components of FRP system must be delivered and stored in the original factory-sealed unopened packaging or containers with proper labels identifying the manufacturer, brand name, system identification number and date. Store catalysts and initiators separately. All components must be protected from dust, moisture, chemicals, direct sunlight, physical damage, fire, and temperatures outside the range specified in the system data sheets. Any component that has been stored in a condition different from that stated above must be disposed of, as specified in Section 3.4.

3.1.2 Shelf Life

All components of the FRP system, especially resins and adhesives, that have been stored longer than the shelf life specified on the system data sheet, shall not be used, and must be disposed of, as specified in Section 3.4.

3.2 Handling

All components of the FRP system, especially fiber sheets, must be handled with care according to the manufacturer recommendations to protect them from damage and to avoid misalignment or breakage of the fibers by pulling, separating or wrinkling them or by folding the sheets. After cutting, sheets shall be either stacked dry with separators, or rolled gently at a radius no tighter than 12 in. (305 mm) or as recommended by the manufacturer.

3.2.1 Safety Hazards

All components of the FRP system, especially resins and adhesives, must be handled with care to avoid safety hazards, including but not limited to skin irritation and sensitization, and breathing vapors and dusts. Mixing resins shall be monitored to avoid fuming and inflammable vapors, fire hazards, or violent boiling. The Contractor is responsible to ensure that all components of the FRP system at all stages of work conform to the local, state, and federal environmental and worker's safety laws and regulations.

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key personnel on similar field applications. The field representative may be employed by either the Contractor/Applicator or the Manufacturer/Supplier.

C3 Storage, Handling and Disposal

C3.1 Storage

C3.1.1 Storage Requirements

These requirements are intended to help preserve properties of FRP system and maintain safety of the work place. The components may include sheets, plates, bars, strips, resins, solvents, adhesives, saturants, putty, and protective coatings. System identification number may be the batch number from the factory. Typically, temperature in the storage area should be within 50°–75°F (10°–24°C), unless otherwise noted on the system data sheet. Typically, components should be stored in a dry environment, unless an acceptable moisture level is specified on the system data sheet.

C3.1.2 Shelf Life

Properties and reactivity of resins and adhesives may degrade with time, temperature or humidity.

C3.2 Handling

Fiber sheets with higher modulus fibers are more susceptible to misalignment damages, and therefore must be handled with greater care. Dusts or residue can enter fiber sheets, if not protected. Rolling pre-cut short lengths of fiber sheets may cause damage through fiber movement and fabric shearing. Contamination of any component of FRP system with an organic solvent may reduce tensile strength and other properties of the cured laminates.

C3.2.1 Safety Hazards

Consult Chapter 9 of the ACI 503R-93 for additional information on safety hazards of epoxy. Ignition or fire in the proximity of epoxy resins could be hazardous. Appropriate references may be used for other types of resin such as vinyl esters. Placing carbon FRP sheets, bars or strips near electrical equipment may cause short-circuit or electrical shock, because carbon is a conductive material. Glass fibers are known to cause severe itching and skin irritation.

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3.2.2 Material Safety Data Sheets

The MSDS for all components of the FRP system shall be accessible to all at project site. Specific handling hazards and disposal instructions shall be specified in the MSDS.

3.2.3 Personnel and Work-place Protection

The Contractor is responsible for providing proper means of protection for safety of the personnel and the work place. The Contractor shall inform the personnel of the dangers of inhaling fumes of primer, putty or resin, and shall take all necessary precautions against injury to personnel. The resin mixing area shall be well vented to the outside.

3.3 Clean-up

The Contractor is responsible for the clean-up of the equipment and the project site from hazardous and aesthetically undesirable FRP components using appropriate solvents, as recommended in the system data sheet.

3.4 Disposal

Any component of the FRP system that has exceeded its shelf life or pot life, or has not been properly stored, as specified in Section 3.1, and any unused or excess material that is deemed waste, shall be disposed of in a manner amiable to the protection of the environment and consistent with the MSDS.

4 Substrate Repair and Surface Preparation

The concrete substrate shall be repaired, if necessary, and all concrete surfaces shall be cleaned and prepared prior to installing the FRP system.

4.1 Removal of Defective Concrete

All defective areas of concrete substrate shall be removed according to ACI 546R-96 and ICRI No. 03730, using appropriate equipment such as air or electric powered jack hammer or saw, at a sufficient depth of at least ½ in. (12.7 mm) beyond the repair area to expose sound aggregates. If any reinforcing or prestressing steel is exposed in the process, and it is either deteriorated or its bond with concrete is broken in the process, an additional nominal depth of ¾ in. (19 mm) or at least ¼ in. (6.4 mm) larger than the largest aggregate in repair material shall be cut from its underneath. If any deterioration is noticed

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C3.2.2 Material Safety Data Sheets

Code of Federal Regulations (CFR 16) regulates the labeling of hazardous substances and includes thermosetting-resin materials.

C3.2.3 Personnel and Work-Place Protection

Safety measures may include protective clothing and devices, such as disposable plastic or rubber gloves, safety glasses or goggles, dust masks, safety gear respirators, fire extinguishers, and ventilators, depending on the FRP system, working conditions, and the job site. Disposable gloves may degrade in presence of vinyl esters and solvents, if not specifically designed for use with FRP system.

C3.3 Clean-up

The Contractor may additionally consult with the prevailing environmental protection and health agencies for proper clean-up of the project site. Some clean-up solvents may be flammable.

C3.4 Disposal

Pot life depends on the system, mixed quantity, and ambient temperature. The Contractor may also consult the prevailing environmental protection and health agencies for proper disposal of FRP components. Allow un-used mixed primer, putty or resin to harden in their containers before disposal.

C4 Substrate Repair and Surface Preparation

A clean and sound concrete substrate is essential to the effectiveness of the FRP system in achieving the design strength and the intended design objectives.

C4.1 Removal of Defective Concrete

Defects may include loose and broken debris or delaminated and spalled sections of concrete, voids and honeycombs, and deteriorated concrete. Defects in concrete substrate can compromise the integrity of the FRP system. Any attempt at covering the deteriorated (carbonated or chloride contaminated) concrete with FRP system without correcting the source of deterioration may be detrimental to the effectiveness of the repair. Investigations to date [*Harichandran and Baiyasi 2000*] have shown that placement of externally bonded FRP, especially when used for full confinement, may arrest cracking of in the repair area, its source shall be located and treated to the satisfaction of the Engineer prior to restoring the section. Upon removing defective concrete, and before restoring the section, the substrate shall be cleaned from any dust, laitance, grease, oil, curing compounds, impregnations, foreign particles, wax and other bond inhibiting materials, as per Section 4.4.6.

4.2 Repair of Defective Reinforcement

All defective reinforcement shall be repaired according to ICRI No. 03730, and to the satisfaction of the Engineer. FRP systems shall not be applied to concrete suspected of containing corroded reinforcement. Corroded or otherwise defective reinforcement that is to be supplemented shall be cleaned and prepared thoroughly by abrasive cleaning to near white appearance. Damaged reinforcement that needs to be replaced shall be cut at sufficient length, according to the Contract Documents and the approval of the Engineer, to ensure full section and sound material in the remaining portion. Splice for the ruptured or cut reinforcing or prestressing steel shall be provided at sufficient length, according to the Contract Documents and approval of the Engineer.

4.2.1 Mechanical Anchorage

Mechanical anchorage of the repair material with the substrate shall be placed, if specified in the Contract Documents. Anchors shall be secured in place by tying to other secured bars, and shall not protrude outside concrete surface. If that is not possible, the concrete surface shall be built up to cover the protrusions.

4.3 Restoration of Concrete Cross Section

The area of removed concrete substrate, and any void larger than ½ in. (12.7 mm) diameter and depth, shall be filled with repair material that conforms to ICRI No. 03733. The repair material shall have a compressive strength equal to or greater than that of the original concrete, but no less than 4,500 and 5,500 psi (31 and 38 MPa) at 7 and 28 days, respectively. The design mix for all repair materials shall be approved by the Engineer. The bond strength of the repair material to the existing concrete shall be a minimum of 200 psi (1.4 MPa) in the pull-off test according to ASTM D4541. The concrete substrate and the exposed reinforcing or prestressing steel shall be clean, sound and free of surface moisture and frost before restoring the section. Before placement of patching materials, a water-based epoxy cementitious bonding agent shall be applied to concrete and exposed reinforcement. Also, cracks

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concrete and slow down the rate of corrosion of steel reinforcement, but does not stop or reverse the corrosion process [*Sohanghpurwala and Scannell 1994*]. Precautions may be necessary in cases of carbonation, alkali-silica reactivity (ASR) or reactive aggregate.

C4.2 Repair of Defective Reinforcement

Defects in the reinforcement may include section loss or rupture due to impact or corrosion. Any attempt at covering the deteriorated section with FRP without arresting the corrosion process may be detrimental to the entire repair, because of the expansive forces associated with corrosion. If not treated properly, repair in one section may lead to an accelerated corrosion in an adjacent section. The exposed steel may be treated by applying corrosion inhibitors prior to restoring the section. The Owner may require other treatment forms for corroded steel, or placement of sensors to monitor the corrosion process. The splice detail is intended to provide strength and ductility in both longitudinal and transverse directions in case the FRP system is lost due to fire, vandalism, or any other cause.

C4.2.1 Mechanical Anchorage

Mechanical steel or plastic anchorage is to ensure adequate bond with the existing cross section, where new concrete patch material is placed. A grid of 4 in. × 4 in. (102 mm × 102 mm) with a minimum embedment depth of 1½ in. (38 mm) is usually adequate. If the anchors protrude outside the concrete surface, they may damage fibers used in the FRP system.

C4.3 Restoration of Concrete Cross Section

The repair material may be an approved polymer/latex modified mortar/concrete or an approved factory bagged mortar/concrete patching material of equal characteristics. It is recommended that the manufacturer be consulted on the compatibility of the repair material with the FRP system. At locations where due to the size of the voids or other constraints, prebagged mortar/concrete can not be used, a Class III latex modified concrete may be used, as approved by the Engineer. No formwork is necessary for small voids, where repair materials may be placed by hand and troweled to match the original section. Formwork for larger areas may be built around the damaged area to ensure that the restored section is smooth and uniform, and that it conforms to the original shape of the section. The instruction for most patching materials specifies a bonding agent, often a diluted mixture of the patching mix rubbed

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within solid concrete in the substrate shall be stabilized using epoxy injection methods, as specified in Section 4.4.3. If water leak through cracks or concrete joints is significant, water protection and a water conveyance and weep holes shall be provided before restoring the section. The repair material shall be cured a minimum of 7 days before installing the FRP system, unless its curing and strength are verified by tests.

4.4 Surface Preparation

All necessary repair and restoration of concrete section shall be approved by the Engineer, prior to surface preparation. In this Specifications, contact-critical applications are treated the same as bond-critical applications. An adhesive bond with adequate strength shall always be provided between FRP and concrete. Surface preparation shall also promote continuous intimate contact between FRP and concrete by providing a clean, smooth, and flat or convex surface. Surface preparation for near-surface mounted FRP bars or strips is specified in Section 4.4.4. Surface preparation for FRP shell systems where grout is pumped into the gap between the shell and the existing column surface is specified in Section 4.4.5. All surface preparations shall be approved by the Engineer, before installing the FRP system.

4.4.1 Surface Grinding

All irregularities, unevenness, and sharp protrusions in the surface profile shall be grinded away to a smooth surface with less than $\frac{1}{32}$ in. (0.8 mm) deviation. Disk grinder or other similar devices shall be used to remove stain, paint, or any other surface substance that may affect the bond. Concrete surface shall be grinded to the concrete surface profile range of CSP 2–3 defined by ICRI as minimum surface roughness level. Voids with diameters larger than $\frac{1}{2}$ in. (12.7 mm) and depressions on the concrete surface deeper than $\frac{1}{16}$ in. (1.6 mm) measured from a 12 in. (305 mm) straight edge placed on the surface, shall be filled according to Section 4.4.5.

4.4.2 Chamfering Corners

All inside and outside corners and sharp edges shall be rounded or chamfered to a minimum radius of $\frac{1}{2}$ in. (12.7 mm) as per ACI 440.2R-02. Ridges, form lines, and sharp or roughened edges greater than $\frac{1}{4}$ in. (6.4 mm) shall need to be ground down or filled with putty, as specified in Section 4.4.5. Obstructions and embedded objects shall be removed before installing the FRP system, if required by the Engineer.

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into the concrete. Curing time depends on the type of patching materials.

C4.4 Surface Preparation

Surface roughness has a significant effect on the bond between FRP system and concrete [*Shen et al. 2002*]. Surface preparation depends on the type of application and the type of FRP system. Even though bond may not be structurally necessary for contact-critical applications such as confinement of columns, it would help improve durability of the structure. Many applications of column wrapping occur in aggressive environments. Any debonding between FRP and concrete that may result due to less stringent criteria could lead to significant damage during freeze-thaw cycles.

C4.4.1 Surface Grinding

Consult with the ACI 546R-96 and ICRI No. 03730 for grinding of concrete surfaces and for assuring proper surface preparation. Vacuum cleaning could help reduce the dusts in environmentally sensitive areas. Test results of NCHRP 10-59 Phase II suggest that surface roughness higher than CSP 2–3 does not necessarily improve bond performance. The same study also shows that void depth does not have an influence on the repair system. On the other hand, valleys deeper than $\frac{1}{16}$ in. (1.6 mm) over 12 in. (305 mm) length could lower flexural strength of FRP systems.

C4.4.2 Chamfering Corners

Chamfering of corners improves bond between FRP and concrete, reduces stress concentrations in FRP, and helps prevent voids between FRP and concrete [*Yang et al. 2001a&b*] (Figure C4.4.2). This is especially critical for carbon FRP systems, because their transverse strength and modulus are substantially lower than their longitudinal values, and therefore, could easily fracture when bent over a sharp edge. Obstructions, reentrant corners, concave surfaces, and embedded objects can affect the performance of the FRP system.

Specifications | **Commentary**

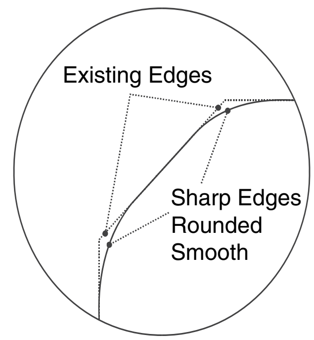

Figure C4.4.2. Chamfering Corners.

4.4.3 Crack Injection

All cracks in the surface of concrete or the substrate wider than 0.01 in. (0.25 mm) and with spacing less than 1.5 in. (38 mm) or cracks wider than 1⁄32 in. (0.8 mm) shall be filled using pressure injection of epoxy according to ACI 224.1R. Smaller cracks may also require resin injection in aggressive environments. Follow ACI 224R-01 crack width criteria for various exposure conditions. FRP system shall be installed no earlier than 24 hours after crack injection. Any surface roughness caused by injection shall be removed as per Section 4.4.1.

C4.4.3 Crack Injection

Movement of cracks wider than that specified may cause delamination or fiber crushing in externally bonded FRP systems. Crack injection helps restore concrete strength and prevent water leakage behind the FRP system. The procedure usually includes cleaning of the cracks, sealing of the surfaces, installing the entry and venting ports, mixing the epoxy, pressure injecting the epoxy, and removing the surface seal. Test results of NCHRP 10-59 Phase II show crack width tolerance of 1⁄100 in. (0.25 mm) to be too conservative, especially if spaced wider than 1.5 in. (38 mm). However, the tolerance is maintained for the purpose of durability of FRP system and internal steel reinforcement.

4.4.4 Grooves for Near-Surface Mounted FRP

A groove with dimensions specified in the Contract Documents shall be made in concrete, where the FRP bar or strip is to be placed. Care shall be taken to avoid local fracture of the concrete surrounding the groove. The groove in which FRP is to be placed shall be free of loose, unsound or bond inhibiting materials such as oil, efflorescence or moisture. All obstructions and embedded objects shall be removed from the groove area, upon approval of the Engineer.

C4.4.4 Grooves for Near-surface Mounted FRP

It is recommended to first examine the existing conditions to assess the quality of the concrete substrate, identify potential obstructions, and verify the dimensions and geometries shown in the Contract Documents. The groove is often made using a grinder or concrete saw with a suitable blade. Embedded obstructions and objects can affect the performance of the FRP system. Test results of NCHRP 10-59 Phase II suggests that groove size tolerance of ± 1⁄8 in. (3.2 mm) may be acceptable for near-surface mounted FRP systems for groove size of 9⁄16 in. (14 mm).

4.4.5 Surface Profiling

After surface grinding, any remaining unevenness in the surface greater than that specified in Section 4.4.3, including out-of-plane variations, fins, protrusions, bug holes, depressions voids, and roughened corners shall be filled and smoothed over using putty made of epoxy resin mortar or polymer cement mortar with strength equal to or greater than the strength of the original concrete. The patching material shall be cured a minimum of 7 days before installing the FRP system, unless its curing and strength are verified by tests.

C4.4.5 Surface Profiling

Consult the ACI546R and ICRI Guideline No. 03730 for surface profiling. Surface profile of the concrete substrate may provide an open roughened texture for pre-cured FRP shell systems, where grout is pumped into the space between the shell and the existing column surface. Curing time depends on the type of patching materials.

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4.4.6 Surface Cleaning

Substrate concrete and finished surface of concrete shall be cleaned to the approval of the Engineer. Cleaning shall remove any dust, laitance, grease, oil, curing compounds, wax, impregnations, stains, paint coatings, surface lubricants, foreign particles, weathered layers or any other bond-inhibiting material. If power wash is used, the surface shall be allowed to dry thoroughly before installing the FRP system. The cleaned surface shall be protected against re-deposit of any bond-inhibiting materials. Newly repaired or patched surfaces that have not cured a minimum of 7 days shall be coated with a water-based epoxy paint or other approved sealers.

Commentary

C4.4.6 Surface Cleaning

This section relates to surface cleaning for the substrate after removal of defective concrete and prior to restoring the concrete section, as specified in Section 4.1. It also relates to surface cleaning of the finished surface of concrete before installing the FRP system. Cleaning may be performed with blast cleaning, air blower, pressure washing, or other equivalent means. Clean wiping rags may also be used for removing any dust that may have been generated on the concrete surface during the grinding operation. Vacuum cleaning could help reduce the dusts in environmentally sensitive areas.

5 Installation of FRP System

This section specifies general installation procedures for three types of FRP systems: wet lay-up, pre-cured, and near-surface mounted. Specific procedures for installing FRP systems may vary slightly for each system and manufacturer.

C5 Installation of FRP System

Contract Documents provide specific procedures for the specific type of FRP system. Other less common FRP systems, such as dry lay-up and machine-applied or automated, are not included in this Specifications.

5.1 Environmental Conditions for Installation

Environmental conditions shall be examined before and during installation of the FRP system to ensure conformity to the Contract Documents and manufacturer's recommendations. Do not apply primers, putty, saturating resins, or adhesives on cold, frozen, damp, or wet surfaces. Ambient and concrete surface temperatures shall be within 50°–90°F (10°–32°C), unless specified by the manufacturer. Moisture level on all contact surfaces shall be less than 4.3% at the time of installation of FRP system, as evaluated according to ACI 503R-93. Moisture restrictions may be waived for resins that have been formulated for wet applications. Relative humidity at the time of FRP application should be in the range of 65%–82%.

5.1.1 Moisture Vapor Transmission

Application of bonded FRP systems shall not proceed, if any moisture vapor transmission is present. Concrete dryness is necessary, when using elevated temperature cure. Any bubble that develops from moisture vapor transmission can effectively be injected with the same adhesive material used for the FRP system, following the procedure specified in Section 7.2.

5.1.2 Applications in Inclement Weather

When inclement weather does not allow installation of FRP system, as specified in Section 5.1, auxiliary measures may be

C5.1 Environmental Conditions for Installation

Moisture may hinder adhesion of the primer and resin. Work may be postponed, if adverse weather, rain or dew condensation is anticipated. Although moisture primarily affects the polymers and concrete surface, it may also collect on the surface of the fiber sheets, if not stored properly, as specified in Section 3.1.1. Moisture on fiber sheets can cause problems with wet-out and cure of the system. Surface moisture may be measured using a mortar moisture meter, or alternatively an absorbent paper. Cold weather may cause improper curing of the resin and saturation of fibers, compromising the integrity of the FRP system.

C5.1.1 Moisture Vapor Transmission

This section only applies to the conditions at the time of construction, and not those that should be addressed in the design process. Moisture vapor transmission from concrete surface through uncured resin may cause air pockets and surface bubbles, compromising bond between FRP system and concrete. These effects have primarily been observed in wet lay-ups, but are not excluded from other FRP systems.

C5.1.2 Applications in Inclement Weather

Different heating systems, such as spotlights, electrical heaters, infrared heating, and heating blankets may be used.

employed to correct the conditions. Auxiliary heat source may be used in cold weather to raise the ambient and concrete surface temperatures to acceptable levels, as recommended by the manufacturer, but no more than the glass transition temperature (T_g). Pressurized air may be used to dry the surface dampness.

Electrical conductivity of carbon fibers may be used to apply a current, thereby providing fast in-situ curing in about 3 hours [*CEB-FIP 2001*]. The maximum elevated temperature depends on the system used. This procedure, however, is not yet widely accepted as providing a uniform and consistent cure profile.

5.2 Shoring

Repaired members shall be shored temporarily with conventional methods, if specified in Contract Documents, or required by the Engineer for safety. Shoring shall not be removed until the FRP system has fully cured and gained its design strength, as recommended by the manufacturer and approved by the Engineer.

C5.2 Shoring

In most applications, the FRP system may be applied, while the structure is in service. Shoring may be provided to either support the existing structure prior to repair, or to reduce its initial deflections prior to strengthening. Shoring may also be used to induce an initial camber in the system, thereby stressing the FRP system.

5.3 Equipment

The Contractor shall provide all necessary equipment, in sufficient quantities and in clean and operating conditions, for continuous uninterrupted FRP installation.

C5.3 Equipment

The equipment may vary for different FRP systems. They may include resin impregnators, rollers, sprayers, and lifting and positioning devices.

5.4 Application of Wet Lay-Up FRP Systems

This section specifies the necessary measures for installing wet lay-up systems using dry or prepreg fiber sheets and saturants.

5.4.1 Mixing of Resin Components

All resin components, including main agent and hardener shall be mixed at proper temperature using appropriate weight ratio and for a duration specified by the manufacturer, until thorough mixing with uniform color and consistency is achieved. Resins shall not be diluted with any organic solvents such as thinner. Manual stirring and small electrically powered mixing blades are allowed. Resin shall be mixed in quantities sufficiently small to ensure that it can be used within its pot life. Any mixed resin that exceeds its pot life, or begins to generate heat or show signs of increased viscosity, shall not be used, and shall be disposed of according to Section 3.4. Mixing of some resins may be accompanied by noxious fumes. Precautions must be taken, as specified in Section 3.2.1, regarding their impact on the environment, including emission of volatile organic compounds and toxicology.

5.4.2 Primer and Putty

A primer coat is generally required in all available FRP systems. Apply one or two coats of primer on the concrete surface to penetrate its open pores. Ambient and concrete surface temperatures must be within the range specified in Section 5.1. The

C5.4 Application of Wet Lay-Up FRP Systems

Wet lay-up systems may alternatively be applied using special equipment (saturator) to automate and speed up the process.

C5.4.1 Mixing of Resin Components

The term *resin* is a generic denomination used to identify all polymers employed in wet lay-up systems. Depending on its function, resin is more specifically identified as primer, putty, and saturant. Not all FRP systems use putty. Excessive agitation, when using electrically powered mixers, may cause froth and bubbles that can be entrapped as voids in the resin. Resin components are often contrasting colors, hence full mixing is achieved when color streaks are eliminated. The stoichiometry of the resin will not be met, unless resin solids at the bottom of the container are completely mixed. Pot life of resin depends on its type and the ambient temperature. Viscosity of a mixed resin that has exceeded its pot life will continue to increase, adversely affecting its ability to penetrate the concrete surface or saturate the fiber sheet.

C5.4.2 Primer and Putty

Primer may be applied using a clean roller or brush. The primer, when applied uniformly, helps hatch and strengthen the most external layer of concrete, and improves the bond between the concrete substrate and the FRP system. The rate

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putty, if used in the FRP system, shall be applied as soon as the primer becomes tack-free or until not-sticky to the fingers. The putty shall be applied within 7 days after primer application; otherwise, the primer coated surface shall be roughened with sandpaper or similar tool. The resulting surface shall be cleaned according to Section 4.4.6, before applying the putty. Apply a thin coat of putty in one or two layers, and smoothen over the surface to fill in any small voids, cracks or uneven areas. Any swelling on the surface after applying the putty shall be corrected to meet surface profile as specified in Section 4.4.5. The surfaces of primer and putty shall be protected from dust, moisture and any other contaminants before applying the FRP.

5.4.3 Saturant

The first coat of saturating resin, *saturant,* shall be uniformly applied as an undercoat to all locations on the concrete surface where the FRP system is to be installed. The saturant shall have sufficiently low viscosity to ensure full impregnation of the fiber sheets prior to curing. To maintain proper viscosity of the saturant, the ambient and concrete surface temperatures must be within the range specified in Section 5.1. Any mixed saturant that exceeds its pot life shall be disposed of, according to Section 3.4.

5.4.4 Applying Fiber Sheet and Saturant

Upon uniformly applying the first layer of saturant as undercoat, the fiber sheet previously cut to the length specified in the Contract Documents, shall be installed in place and gently pressed onto the wet saturant. Any entrapped air between fiber sheet and concrete surface shall be released or rolled across the sheet in the direction parallel to the fibers, while allowing the resin to impregnate the fibers and achieve intimate contact with the substrate. Rolling perpendicular to the fiber direction is not allowed. In bi-directional fabrics, rolling shall be initially in the fill direction end to end, and then in the warp direction. Sufficient saturant shall be applied on top of the fiber sheet, as overcoat, to ensure full saturation of the fibers. Undercoat, fiber sheets and overcoat shall be applied with no interruption.

5.4.5 Multiple Fiber Plies

In multi-ply installations, the sequence specified in Section 5.4.4 shall be repeated for each additional fiber sheet. The amount of resin overcoat for intermediate plies is approximately 15%–20% greater than a single-ply installation, because the saturant serves as overcoat for the applied ply and undercoat for the next ply. Follow the Contract Documents for the fiber orientation and ply stacking sequence. Each ply shall be applied before the onset of complete gelation of the previous layer. The number of plies that can be applied in a single day

Commentary

of surface coverage of primer is typically listed in the system data sheet. Not all FRP systems use putty. The primary function of the putty, if used, is to smoothen the concrete surface. The putty may be applied using a clean towel or spatula or any other suitable method. Adding silicate sand to the putty may improve its stability and prevent its swelling.

C5.4.3 Saturant

The resin which impregnates the fibers is the key component to form the FRP laminate that repairs or retrofits the concrete member. Rate of coverage of the resin is listed on the system data sheet, but it generally depends on the type of resin, the ambient temperature, and the porosity of concrete surface. Typical rate of application is about 0.1 lb/ft^2 (4.9 kg/m^2).

C5.4.4 Applying Fiber Sheet and Saturant

This installation procedure is for a single fiber sheet or the first fiber sheet or ply in a multi-ply application. Alternatively, the fiber sheet may be separately impregnated using a resin-impregnating machine before placement on the concrete surface. For ease of handling and to avoid wrinkling, fiber sheets are typically cut in segments shorter than 15 to 20 ft (4.6 to 6.1 m) lengths. Metal serrated rollers are often used to force resin between fibers and to remove entrapped air. However, when used with excessive force, these rollers may cause fracture of the fibers. Rolling perpendicular to the fiber direction may misalign or damage the fibers.

C5.4.5 Multiple Fiber Plies

Some repair and retrofit applications may require more than a single fiber ply to be installed by wet lay-up. The waiting time between plies depends on the type of resin, type of fiber sheet, and ambient temperature. It is good practice to wait for the resin to fully impregnate the fibers to avoid forming air pockets. Rate of coverage of the resin overcoat is listed on the system data sheet, but it generally depends on the type of resin and fibers and the ambient temperature. Typical rate of application is about 0.05 lb/ft^2 (2.4 kg/m^2). Application of

Specifications

shall be determined based on the manufacturer's recommendation and the approval of the Engineer. Multiple plies can also be applied in several days. When previous layers are cured, interlayer surface preparation, such as light sanding and filling with putty may be required, as specified in Section 5.4.2.

5.4.6 Overlapping

A lap joint shall be constructed when an interruption occurs in the direction of the fibers. The length of lap splice shall be as specified by the Contract Documents, but at least 6 in. (152 mm). Staggering of lap splices on multiple plies and adjacent strips shall be required, unless permitted by Contract Documents. No lap joint is necessary in the transverse direction, unless specified in the Contract Documents.

5.4.7 Alignment of FRP Materials

The fiber plies shall be aligned on the structural member according to the Contract Documents. Any deviation in the alignment more than 5° (approximately 1 in./ft or 87 mm/m) is not acceptable, as specified in Section 6.3. Once installed, the fibers shall be free of kink, folds and waviness.

5.4.8 Anchoring of FRP Sheets

Anchoring of FRP sheets to the concrete substrate shall follow the method specified in the Contract Documents, or approved by the Engineer. When using mechanical clamps and fasteners, care shall be taken to avoid damage to the FRP system or to the concrete substrate. Precautions shall be taken when steel fasteners are used for carbon FRP to avoid galvanic corrosion. FRP anchors shall be sufficiently embedded into concrete.

5.4.9 Stressing Applications

Stressing of FRP systems shall follow the method specified in Contract Documents. Active end anchorages shall be used for linear prestressing. For circular prestressing of wet lay-up systems, the gap left between the FRP system and the concrete column shall be filled using expansive mortar or pressure injection of epoxy grout, as specified in Section 5.5.4.

5.5 Application of Pre-Cured FRP Systems

Installation of pre-cured FRP systems is generally similar to single ply wet lay-up. Surface preparation of the concrete substrate shall provide an open roughened texture.

5.5.1 Application of Adhesive

Apply the adhesive uniformly onto all surface areas of concrete substrate where the pre-cured FRP system is to be

Commentary

too many plies in a single day may result in slippage or separation due to self-weight of fiber sheets. The number of plies that can be applied in a single day depends on the ambient temperature, weight of fiber sheet, and whether the repair is overhead or on a vertical surface.

C5.4.6 Overlapping

When the length of the sheet to be installed exceeds the length suggested by the manufacturer for proper installation, lap jointing becomes necessary. Lap splice length depends on the type of resin and fibers [*Yang and Nanni 2002, Belarbi et al. 2002*]. For large coverage areas, it is recommended that all lap joints in the longitudinal direction of fibers be made in a single day. Transverse lap joints, if necessary, may be made in several days.

C5.4.7 Alignment of FRP Materials

Performance of unidirectional FRP system depends heavily on fiber orientation and straightness. Misalignment may occur due to improper rolling or wrong placement of fiber sheets. Fiber misalignment is known to affect the strength more significantly than the elastic modulus [*Yang et al. 2002*].

C5.4.8 Anchoring of FRP Sheets

Anchoring of fiber sheets helps prevent delamination failure of the FRP system. Different methods can be employed to anchor the fiber sheets. When possible, U-wraps may provide additional anchorage against premature delamination of the FRP system.

C5.4.9 Stressing Applications

Stressing and active confinement with glass FRP system is NOT recommended due to concerns related to its creep rupture. The prestrain in carbon should be limited to 50% of the ultimate strain due to damage tolerance concerns with unidirectional carbon FRP.

C5.5 Application of Pre-Cured FRP Systems

Pre-cured FRP systems consist of laminates in the form of plates, strips, open grid forms, or shells. These systems are typically installed with an adhesive resin.

C5.5.1 Application of Adhesive

Adhesives may be applied with a spatula or any other suitable method. Rate of coverage of the adhesive is listed on the

Specifications

installed. Thickness and viscosity of the adhesive layer shall be according to the manufacturer's recommendations. Ambient and concrete surface temperatures must be within the range specified in Section 5.1, prior to applying the adhesive. Any mixed adhesive that exceeds its pot-life shall be disposed of, as specified in Section 3.4.

5.5.2 Placement of Pre-Cured System

Pre-cured FRP system shall be cleaned, cut to the length specified in the Contract Documents, and placed into the wet adhesive within the pot life of the adhesive. Entrapped air between laminate and concrete shall be released, and excess adhesive shall be removed. Do not disturb the applied FRP system before the adhesive fully cures.

5.5.3 Anchoring of Pre-Cured System

Anchoring of pre-cured systems is typically the same as the FRP sheets, as specified in Section 5.4.8.

5.5.4 Grouting of Pre-Cured Shells

Pre-cured shells around concrete columns shall be grouted no less than 24 hours after installation. Pressure grouting shall follow the Contract Documents and the manufacturer recommendations. The grout shall have a shrinkage strain of less than 0.0005 and a compressive strength greater than 4,000 psi (27.6 MPa).

5.5.5 Stressing Applications

Installation of prestressed FRP systems begins requires a moveable anchorage, which usually consists of gluing the FRP laminate termination between two steel plates, held in place by means of screws. After curing of the moveable anchorage, the fixed anchorage at the other end of the member shall be installed, and the FRP laminate shall be glued between a steel plate and the concrete surface. Fasten the steel plate to the concrete surface using inserts. The fixed anchorage must be cured, before the FRP laminate can be stressed. Install another fixed anchorage on the concrete surface at the other end of the member using insert. Once the two fixed anchors have been installed, the system is ready for stressing with hydraulic jacks. During the prestressing process, an epoxy gel is spread uniformly on the entire concrete surface where the laminate has contact. The thickness of the epoxy gel shall follow the manufacturer's recommendation. Any entrapped air shall be released by pressing on the FRP. After the epoxy gel has cured, the moveable anchor is removed and the laminate is cut. Both fixed anchors remain in place.

Commentary

system data sheet, but it generally depends on the type of resin, the ambient temperature, and the porosity of concrete surface. Typical rate of application is about 0.1 lb/ft^2 (4.9 kg/m^2). The adhesive is not necessary, when an intentional gap is left between concrete surface and the FRP shell, to be later filled with grout, as specified in Section 5.5.4.

C5.5.2 Placement of Pre-Cured System

Since there are a number of different pre-cured systems, it is important to follow the manufacturer's recommendations on the timing and sequence of stacking, overlap and banding, horizontal and vertical joints, staggering of splices and overlap and butt joints. The use of a dust mask is recommended when cutting pre-cured FRP systems.

C5.5.3 Anchoring of Pre-Cured System

Temporary clamping and shoring may be necessary in overhead applications of the pre-cured systems until the adhesive cures.

C5.5.4 Grouting of Pre-Cured Shells

Pressure grouting creates an active confinement in the column. Active confinement with glass fiber systems is NOT recommended due to concerns related to creep rupture. The prestrain in carbon should be limited to 50% of its ultimate strain, as described in Section C5.4.9.

C5.5.5 Stressing Applications

Prestressed FRP systems often require proprietary materials, procedures, and anchoring system. The stressing hardware may be found on the shop drawings, as specified in Section C2.1. The movable anchorage generally cures in 24 hours, while the fixed anchorage takes about 48 hours to cure. Prestressing of glass FRP system is NOT recommended due to concerns related to creep rupture. Prestressing of carbon FRP system above 50% of the ultimate strain may affect its damage tolerance, hence requiring additional protection against accidental impact

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5.6 Application of Near-Surface Mounted FRP Systems

Near-surface mounted (NSM) FRP system is an alternative to externally bonded FRP systems. In this system, a bar or strip is inserted and anchored into a pre-cut groove, as specified in Section 4.4.4. The NSM FRP system shall not be installed when surface moisture is present on the substrate or when rainfall or condensation is anticipated.

5.6.1 Application of Embedding Paste

Components of the embedding paste shall be mixed by the ratio specified by the manufacturer, until thorough mixing with uniform color and consistency is achieved. All grooves, where the NSM FRP system is to be placed, shall be half-filled with the paste. Ambient and concrete surface temperatures must be within the range specified in Section 5.1, prior to applying the paste. Mixed paste that exceeds its pot-life shall be disposed of, as specified in Section 3.4.

5.6.2 Placing FRP Reinforcement

The round FRP bar or rectangular FRP strip, shall be cleaned, cut to the length specified in the Contract Documents, placed at mid-depth of the groove, and lightly pressed so as to force the paste to flow around it and completely fill the space between FRP and the sides of the groove. The groove shall then be fully filled with additional paste and the surface be leveled.

5.7 Curing

The FRP system shall be allowed to cure, as recommended by the manufacturer. Field modification of resin chemistry for rapid curing is not allowed. Elevated cure temperature may be used, as specified in Section 5.1.2, if rapid curing is necessary. Cure of installed plies shall be monitored before placing subsequent plies. In case of any curing irregularity, installation of subsequent piles shall be halted. Unless otherwise noted in the Contract Documents and approved by the Engineer, full load shall not be applied until curing is complete. Protect the FRP system while curing, as specified in Section 5.9.

5.8 Protective Coating and Finishing

Protective coating shall be applied on the surface of the FRP system. The coating shall be non-vapor-barrier, flexible, waterproofing, and compatible with the FRP system. The coating may be a polymer-modified Portland cement coating or a polymer-based latex coating. The mortar finish shall be made with silicate sand between sieves No. 40 (1⁄64 in. or 0.42 mm) and

Commentary

C5.6 Application of Near-Surface Mounted FRP Systems

The NSM FRP system allows anchoring the reinforcement into adjacent members, and upgrading members in their negative moment region without exposure to any potential mechanical or abrasion damage.

C5.6.1 Application of Embedding Paste

Any void that develops between concrete substrate and the embedding paste can be detrimental to the performance of the NSM FRP system.

C5.6.2 Placing FRP Reinforcement

FRP bars and strips may be cut with a high-speed grinding cutter or a fine blade saw. FRP bars or strips should not be sheared. The use of a dust mask is recommended when cutting FRP bars or strips. There is not yet sufficient data to support prestressing of NSM FRP systems.

C5.7 Curing

Curing is a time and temperature-dependent process, and may take several days in ambient temperature. In some FRP systems, pressure must be continuously applied through external means to prevent sag and pull-off during cure.

C5.8 Protective Coating and Finishing

Protective coating is applied for aesthetics appeal or protection against impact, fire, ultra violet and chemical exposure, moisture, or vandalism. FRP systems are usually durable to weather conditions, sea water, and many acids and chemicals. Mortar finish can provide protection against impact or fire. Weather-resistant paint of the family of urethane or fluorine or

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No. 6 (⅛ in. or 3.36 mm), spread over the FRP system before the resin hardens. Appropriate methods shall be used for vertical or overhead work. The thickness of the coating shall be specified in Contract Documents. Final appearance is to match, within reason, the color and texture of the adjacent concrete. Surface preparation shall be as recommended by the manufacturer. Solvent-wipes shall not be used to clean the FRP surface, unless approved by the FRP manufacturer. If abrasive cleaning is necessary, air pressure shall be limited to avoid any damage to fibers. Ambient and surface temperatures shall be within the range specified in Section 5.1, prior to applying the protective coating. Do not apply the coating when surface moisture is present or when rainfall or condensation is anticipated.

5.9 Temporary Protection

Temporary protection shall be installed, as specified in Contract Documents, until the resin has fully cured, as approved by the Engineer.

6 Inspection and Quality Assurance

All inspections and tests in this section will be performed by a trained inspector, acting on behalf of the Owner for quality assurance of the project, in the presence of the Contractor and the Engineer. The Contractor may have its own inspector for quality control.

6.1 Inspection of Materials

Manufacturer's certifications for all delivered and stored FRP components will be inspected for conformity to the Contract Documents before starting the project. Materials testing will be conducted on samples of pre-cured or NSM FRP or witness panels of wet lay-ups, if specified in the Contract Documents. Any material that does not meet the requirements of the Contract Documents will be rejected. Additional witness panels may be taken during the installation process, if specified in the Contract Documents.

6.2 Daily Inspection

Daily inspection will include date and time of repair; ambient and concrete surface temperatures; relative humidity; general weather conditions; surface dryness per ACI 503.4; surface preparation and surface profile using ICRI surface-

Commentary

epoxide can provide protection against direct sunlight. The amount of paint finish coat is usually indicated in the shop drawings, as specified in Section C2.1. Use of solvent-wipes may cause deleterious effects on polymer resins. Abrasive cleaning is generally not required, when the first coat of paint is applied within 2–3 days after mixing of the components for the final 15 mil resin coating. It is a good practice to allow a minimum of 1–2 hours before applying the second coat. The Engineer may request the Contractor to provide a sample mock-up of the coating system for about 1 ft^2 (0.1 m^2) area.

C5.9 Temporary Protection

Temporary tents or plastic screen may help protect the installed FRP system against rain, dust, dirt, excessive sunlight, extreme temperatures, and high humidity. They may also serve as deterrence for vandalism.

C6 Inspection and Quality Assurance

The specific quality assurance plan for each project may be developed from the tests identified in this section, based on the size and complexity of the project. Checklists for quality assurance are provided in the accompanying Process Control Manual.

C6.1 Inspection of Materials

Testing in this section is for acceptance and not for qualification. For qualification testing, consult with the AASHTO Materials Specifications for FRP Systems, when it becomes available. The extent of materials testing depends on the size and complexity of the project. Testing may include tensile strength and modulus, glass transition temperature (T_g), pot life, adhesive shear strength, lap splice strength, and hardness, according to ASTM standards, such as ASTM D3039.

C6.2 Daily Inspection

Consult ACI 440.2R-02 and the checklists in the accompanying Process Control Manual for daily inspection and record keeping. The Owner is recommended to retain the inspection records and witness panels for at least 10 years.

profile-chips; qualitative description of surface cleanliness; type of auxiliary heat source, if any; widths of cracks not injected with epoxy; fiber or precured laminate batch numbers and their locations in structure; batch numbers, mixture ratios, mixing times, and qualitative descriptions of the appearance of all mixed resins, primers, putties, saturants, adhesives, and coatings; observations of progress of cure of resins; conformance with installation procedures; adhesion test results: bond strength, failure mode, and location; FRP properties from tests of field sample panels or witness panels, if required; location and size of any delaminations or air voids; and general progress of work.

6.3 Inspection for Fiber Orientation

Fiber or ply orientation, fiber kinks and waviness will be examined by visual inspection for conformity to the Contract Documents. Tolerances will follow Section 5.4.7. Nonconforming FRP area will be removed, and repaired as per Section 7.4.

C6.3 Inspection for Fiber Orientation

See Section C5.4.7 for an explanation of the importance of fiber alignment and straightness.

6.4 Inspection for Debonding

After at least 24 hours for the initial cure of the resin, a visual inspection of the surface will be performed for any swelling, bubbles, voids or delaminations. If an air pocket is suspected, an acoustic tap test will be carried out with a hard object to identify delaminated areas by sound, with at least one strike per 1 ft^2 (0.1 m^2). Defects smaller than ¼ in. (6.4 mm) diameter will require no corrective action, unless as specified in Section 7.2. Defects larger than ¼ in. (6.4 mm) but smaller than 1¼ in. (32 mm) diameter will be repaired as per Section 7.2. Defects larger than 1¼ in. (32 mm) but smaller than 6 in. (152 mm) diameter, and frequency of less than 5 per any unit surface area of 10 ft (3 m) length or width will be repaired as per Section 7.3. Larger defects will be repaired as per Section 7.4.

C6.4 Inspection for Debonding

The inspector may look for changes in color, debonding, peeling, blistering, cracking, crazing, deflections, indications of reinforcing-bar corrosion, and other anomalies. Significance of debonding defects depends on their size, location, and quantity relative to the overall application area. Additional tests such as ultrasonic scanning [*Littles et al. 1996*], microwave detection [*Hughes et al. 2001*] or infrared thermography [*Mandic et al. 1998*] may be performed, if specified in the Contract Documents or approved by the Engineer, when an area is deemed to be suspect.

6.5 Inspection for Cure of Resin

If specified in the Contract Documents, relative cure of resin in FRP systems will be examined by visual inspection, or laboratory testing of witness panels or resin-cup samples using ASTM D3418. Follow recommendations of the resin manufacturer for acceptance criteria. If cure of resin is found unacceptable, the entire area will be marked and repaired as per Section 7.4.

C6.5 Inspection for Cure of Resin

Data on resin cure time and temperature is specified on system data sheets. The sampling frequency depends on the size and complexity of the project. For visual inspection of the cure of resin, the inspector may use physical observation of resin tackiness and hardness of work surfaces or hardness of resin-cup samples.

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6.6 Inspection for Adhesion

After at least 24 hours for the initial cure of the resin and before applying the protective coating, direct pull-off test will be performed following ASTM D4541 to verify tensile bond between FRP system and concrete. Test locations and sampling frequency are as specified on the Contract Documents, or recommended by the Contractor and approved by the Engineer. At a minimum, three pull-off tests with at least one test per span or one test per 1000 ft^2 (93 m^2) of the FRP system, and one test per substrate concrete type will be performed. Inspect failure surface of the core specimen to ensure that it is by cohesive failure within concrete. Failure at the bond line at tensile stresses below 200 psi (1.4 MPa) is unacceptable. If one or more of the pull-off tests is found unacceptable the work will be rejected, and repair will follow Section 7.4. Repair cored areas as per Section 7.3.

6.7 Inspection for Cured Thickness

If specified in the Contract Documents, or required by the Engineer, ½ in. (12.7 mm) diameter core samples will be taken to inspect the cured laminate thickness and number of plies. Sampling frequency will be the same as that specified in Section 6.6, unless otherwise specified in the Contract Documents. Repair cored areas as per Section 7.3. The FRP system will be not acceptable, if the number of plies is less than that specified in the Contract Documents, or if the cured thickness of the FRP system is less than that specified in the Contract Documents by more than 1/32 in. (0.8 mm). The entire area of FRP system marked unacceptable will be repaired as per Section 7.4.

6.8 Load Tests

If specified in the Contract Documents, an in-situ conventional load testing will be conducted on the retrofitted structure.

6.9 Auxiliary Tests

If specified in the Contract Documents, auxiliary tests on witness panels will be carried out. The most common is the tensile test following ASTM D3039 on at least 5 witness panels for each type of FRP system to measure strength, elastic modulus, and ultimate strain. The measured thickness of the FRP laminate will also be recorded. The FRP system will be not acceptable, if the average tensile strength or the lowest tensile strength are more than 5% and 10% below that specified in the Contract Documents, respectively.

Commentary

C6.6 Inspection for Adhesion

The sampling frequency depends on the size and complexity of the project. It is recommended that test locations be on flat surfaces and representative of the variations in the FRP system and the concrete substrate. If possible, test areas need to be selected, where lower stresses are expected during service conditions. Other adhesion tests such as surface adherence shear test or torque test may be used, if specified in the Contract Documents or approved by the Engineer. It is recommended that an initial pull-off test be conducted on 1 ft^2 (0.1 m^2) sample coverage of FRP system on the concrete substrate before the installation proceeds. This will ensure that the FRP system will work effectively.

C6.7 Inspection for Cured Thickness

The sampling frequency depends on the size and complexity of the project. Instead of taking additional cores, the same samples from the adhesion tests may be used for measurement of the cured thickness. If possible, core samples should not be taken from high-stress or lap splice areas.

C6.8 Load Tests

The Owner may anticipate in the Contract Documents a load rating of the structure upon completion of the project.

C6.9 Auxiliary Tests

The Owner may anticipate in the Contract Documents additional tests for durability and accelerated aging of the FRP system with its protective coating against moisture, chemicals and UV radiation. Other auxiliary tests may include inter-laminar shear strength of FRP systems following ASTM D3165 or D3528.

Specifications

7 Repair of Defective Work

This section specifies the conditions and types of defects that require repair, and the acceptable methods of repair. Defects are of different types, and may be generally classified as aesthetic, short-term critical, or long-term critical. Repair procedure depends on the type, size and extent of defects. Repair procedures for any condition not addressed in this Specifications or in the Contract Documents shall be submitted by the Contractor and approved by the Engineer prior to proceeding with the work.

7.1 Repair of Protective Coating

Defects in protective coating can be of three types: small hairline cracks, blistering, and peeling. In all cases, moisture content of the substrate should be below 0.05% before applying a new coating. Prior to any repair of protective coating, the FRP system shall be examined visually or otherwise to ensure that no defect exists within or on the surface of the FRP. Defects in FRP, if found, shall be repaired as per Sections 7.2–7.5. If protective coating appears to show small areas with cracks, the local surface shall be lightly sanded. Then, a new coating with appropriate primer shall be applied based on the manufacturer's recommendations. At the minimum, the coating shall be applied over an area extending 1 in. (25 mm) on either side of the defect. If the protective coating shows signs of blistering, the entire area of blisters as well as the surrounding area to a distance of at least 12 in. (305 mm) shall be carefully scraped clean. In no case, should a blistered surface be re-coated without complete removal of the existing coating. The area shall be wiped clean and then dried thoroughly. Once dry, the area can be re-coated after application of the primer coat, if required by the manufacturer. If the surface shows signs of excessive peeling, the entire coating shall be scraped off, and the surface lightly sanded, wiped cleaned and thoroughly dried, before applying a new coat according to the manufacturer's recommendations.

7.2 Epoxy Injection of Small Defects

Small entrapped voids or surface discontinuities no larger than ¼ in. (6.4 mm) diameter shall not be considered defects, and require no corrective action, unless occurred next to edges or when there are more than 5 such defects in an area of 10ft^2 (0.9 m^2). Small defects of size between ¼ and 1¼ in. (6.4 and 32 mm) diameter shall be repaired using low pressure epoxy injection, as long as the defect is local and does not extend

Commentary

C7 Repair of Defective Work

Defects in FRP systems [*Kaiser and Karbhari 2001a&b*] may include (1) voids and air encapsulation between concrete and layers of primer, resin or adhesive, and within the FRP system itself; (2) delaminations between layers of FRP system; (3) broken or damaged edges of the FRP system; (4) wrinkling and buckling of fiber and fiber tows; (5) discontinuities due to fracture of fibers, breakage in the fabric, or cracks in pre-cured shells; (6) cracks, blisters and peeling of the protective coating; (7) resin-starved areas or areas with non-uniform impregnation or wet-out; (8) under-cured or incompletely cured resin; and (9) incorrect fiber orientation.

C7.1 Repair of Protective Coating

Although primarily aesthetic in nature over the short-term, defects in protective coating may cause long-term degradation of the FRP system due to concentrated moisture ingress. Local defects in coatings are analogous to cracks or blistering in epoxy coating of steel bars. Surface cracks may develop due to a variety of reasons. They are often non-structural, and may be due to excessive coating thickness, excessive shrinkage during cure, or external abrasion. Sandblasting and rotary water pressure should not be used to remove the coating as they leave small pits and craters that cause damage to the FRP system. Blisters are caused when moisture passes through the outermost layer and then causes the development of osmotic pressure from within. Blister is often a sign of moisture entrapment, and hence all moisture needs to be removed prior to applying another coat to ensure that further damage is not caused after re-coating. Large localized blisters are often a result of solvent softening of the coating. Spot repairs should be conducted with a two-part epoxy only. Signs of excessive peeling indicate that the original coating was applied incorrectly most often due to inappropriate surface preparation of the FRP system. Applying a new coating directly on top of the old peeling or any defective coating encapsulates the defects and accelerates internal degradation, which in turn cause rapid deterioration of the new coating itself.

C7.2 Epoxy Injection of Small Defects

Defects at edges or regions of discontinuity, no matter how small, can serve as stress risers that lead to rapid delaminations and growth of other types of defects. Care should be taken to ensure that the internal pressure caused between FRP layers due to injection does not cause further delaminations. Large disbonds close to the edge should not be injected but should be cut open and patched.

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through the complete thickness of the laminate in case of multi-ply FRP systems. If any delamination growth is suspected between the FRP plies due to injection, the procedure shall be halted, and repair shall follow Section 7.3.

7.3 Patching of Minor Defects

Minor defects are those with diameter between 1¼ and 6 in. (32 and 152 mm), and frequency of less than 5 per any unit surface area of 10 ft (3 m) length or width. The area surrounding the defects to an extent of at least 1 in. (25 mm) on all sides shall be carefully removed. The area shall be wiped cleaned and thoroughly dried. The area shall then be patched by adding an FRP patch of the same type of the original laminate and extending at least 1 in. (25 mm) on all sides of the removed area. Repair can also be conducted using the procedure in Section 7.4.

7.4 Replacement of Large Defects

Defects large than 6 in. (152 mm) diameter shall be carefully marked and scarfed out extending to a minimum of 1 in. (25 mm) on all sides. Scarfing shall be progressive through the layers, in the case of multi-ply FRP systems until past the defective area. In case the defect extends to the first FRP ply adjacent to the concrete, the entire thickness of FRP and primer shall be removed. The substrate shall be appropriately prepared and primer re-applied after ensuring that the surface and FRP are clean and dry. Application of a new FRP system within the scarfed area shall follow procedures for the original FRP system, except that an additional layer extending a minimum of 6 in. (152 mm) on all sides of the scarfed area shall be added as a patch. Once cured, the protective coating shall be applied over the entire area.

8 Measurement and Payment

8.1 Method of Measurement

Measurement shall be taken as follows:

- Substrate repair, including removal of unsound concrete, sandblasting, cleaning of reinforcement and concrete, furnishing and placing new concrete, surface preparations, and all other incidentals by lump sum;
- Crack repair by epoxy injection by the linear meter (linear foot) of the injected cracks;
- Furnishing and placing corrosion inhibitors by the square meter (square foot) of concrete surface;

Commentary

C7.3 Patching of Minor Defects

Minor defects to the FRP system may include cracking, abrasion, blemishes, chips, and cuts. The FRP patches should have the same characteristics (e.g., thickness, fiber orientation, ply stacking, resin type, etc.) as the original laminate over damaged area of which it will be bonded. Extending the FRP patch on all sides of the removed area helps with the load transfer. Recent study by Delaney and Karbhari (2006) recommends epoxy injection of minor disbonds for durability purposes.

C7.4 Replacement of Large Defects

Large defects are generally indications of significant debonding between layers, lack of adhesion to the concrete substrate, or extended moisture entrapment causing resin degradation. They may include peeling and debonding of large areas, and non-local defects that may require full replacement. Large defects should be carefully examined, since they may be symptomatic of either significant short-term degradation or poor quality of materials or installation. If the extent of the defect is large and in areas of critical to the structural integrity, it may be advisable to completely remove and re-apply the entire FRP system.

C8 Measurement and Payment

C8.1 Method of Measurement

For small projects, the substrate repair may be considered incidental to the FRP system. Often, upon removal of concrete, additional deteriorated areas may be delineated that warrants further undercutting and treating of the substrate or the reinforcement. The Owner may require the Contractor to obtain approval from the Engineer before extending the limits of concrete removal from those clearly identified in the Contract Documents. Crack injections may also be measured as number of locations, crew days, or lump sum.

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- Furnishing and placing wet lay-up FRP system by the square meter (square foot) of each layer applied;
- Furnishing and placing pre-cured FRP system by the square meter (square foot) of each layer applied, accounting for different layer thicknesses;
- Furnishing and placing near-surface mounted FRP system by the linear meter (linear foot) of each bar or strip; and
- Furnishing and placing protective coating for the FRP system by the square meter (square foot) of each layer of coating applied.

8.2 Basis of Payment

Payments shall be made as follows:

- "Substrate Repair" as lump sum;
- "Crack Injection" per linear meter (linear foot);
- "Furnishing and Placing Corrosion Inhibitors" per square meter (square foot);
- "Furnishing and Placing Wet Lay-up FRP System" per square meter (square foot);
- "Furnishing and Placing Pre-Cured FRP System" per square meter (square foot);
- "Furnishing and Placing Near-Surface Mounted FRP System" per linear meter (linear foot); and
- "Furnishing and Placing Protective Coating" per square meter (square foot).

Commentary

C8.2 Basis of Payment

For small projects, the substrate repair may be considered incidental to the pay item of the FRP system. The Owner may also place limits on the Substrate Repair pay item by requiring the Contractor to receive approval from the Engineer on the limits of the removal area.

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ATTACHMENT B

Recommended Process Control Manual

The proposed Process Control Manual is the recommendation of NCHRP Project 10-59B staff at Florida International University. This manual has not been approved by NCHRP or any AASHTO committee or formally accepted for adoption by AASHTO.

General Policy Statement on Quality Assurance

General Policy Statement on Quality Assurance

The primary objective of the Process Control Manual is to ensure that bonded repair and retrofit of concrete structures using FRP composites is constructed in a manner, which conforms to contractual and regulatory requirements. Determination of conformance of the Contractor's work to the requirements is verified on the basis of objective evidence of quality. This document supplements the Construction Specifications for Bonded Repair and Retrofit of Concrete Structures using FRP Composites.

The process control procedures and the systems outlined herein describe how the Quality Assurance (QA) Program is designed to assure that all quality and regulatory requirements are recognized and that a consistent and uniform control of these requirements is adequately established and maintained.

The success of the QA Program depends on (a) thorough understanding of its aims, and (b) its full implementation by the Owner's representatives.

1 Quality Assurance Policy and Program Overview

1.1 Quality Assurance Policy

The QA Program has been developed to assure that project is carried out in a planned, controlled and correct manner. It includes procedures for scheduling and assigning work; recording, retention and retrieval of records for all construction activities; identifying and resolving deficiencies affecting the work; and verifying compliance with the requirements of the QA Program.

The QA Program can be modified, if necessary, to meet the needs of individual projects, or to comply with any specific requirements or agreements. The program will implement those requirements and agreements by applying them to specific activities, and will identify the items and services to which the program applies.

The QA Procedures (QAP) define the organizational structure within which the program is to be implemented, and delineate the responsibility and authority of the various personnel involved.

The QA Program will be periodically reviewed, audited and updated for improvement, as necessary.

1.2 Quality Assurance—An Overview

1.2.1 Quality Definitions

- Quality Assurance (QA)—Established philosophy, programs and organization covering activities, whose purpose is to provide assurance that the overall quality control program is being effectively implemented.
- Quality Control (QC)—A planned system of activities, whose purpose is to provide a level of quality that meets the needs of users.

1.2.2 QA/QC Goals

- Develop staff understanding and acceptance of QA philosophy and procedures.
- Develop staff understanding of their particular role in implementing QA/QC Procedures.
- Meet the Owner's need for quality product.
- Ensure that appropriate procedures are followed at each step of the process from the inspection of incoming raw materials to the application of final coating to achieve specified performance.

1.2.3 Elements of QA Program

- Program guidelines: setting out QA philosophy and QC procedures.
- Establishment of corporate and office QA staff functions.
- Seminars on QA philosophy and QC procedures and other aspects relating to high quality services and deliverables.
- Implement QA/QC procedures.
- Monitor adherence to policy and procedures.
- Monitor schedule adherence and check deliverables at milestones.
- Identify the type of contract to be signed, and check for unrealistic responsibilities, warranties, indemnifications and ambiguous wording.

2 QA Guidelines for Construction Activities

2.1 Responsibilities

2.1.1 QA Manager

The QA Manager is responsible for the development and the implementation of the QA Program and for ensuring adherence thereto. The QA Manager monitors and audits all project activities on a systematic basis, documents the findings in project audits, and reports the findings to the Unit Manager, the Project Manager, or Technical Department Managers, as appropriate. The QA Manager also identifies the corrective measures for all non-compliances with the QA Program. The QA Manager has the overall authority of initiating, redirecting or terminating activities, so that they are consistent with the QA

Program. The QA Manager may (a) initiate any activities, which will ensure adherence to the QA Program; and (b) utilize the personnel necessary to properly administer the QA Program. Specific duties of the QA Manager include the following:

1. Developing, modifying, updating and implementing the QA Program.
2. Assisting the Unit Managers in implementing the provisions of the QA Program.
3. Assisting the Project Manager in establishing project specific QA requirements, based on the Owner's special needs and the established standard procedures.
4. Instructing project personnel in utilizing the QA procedures.
5. Monitoring adherence to the QA Program.
6. Approving QA Programs of Contractors, Subcontractors, and Consultants, where required.
7. Providing input for reports, specifications, and other documents, where QA information is required.

2.1.2 Project Officer

The Project Officer is responsible for the preparation of Letters of Interest and Proposals, and for assisting in negotiations and finalizing of the Contract. Specific duties of the Project Officer during different phases include the following:

1. During the proposal phase:
   a. Developing the project scope, in conjunction with the Owner's goals and objectives.
   b. Determining QA Program requirements and special QA procedures to be followed in the work process.
   c. Establishing the proposed project budget, schedule and manpower requirements.
   d. Directing the preparation of Letters of Interest, Proposals and Contracts.
   e. Participating in the negotiations.
   f. Signing of the Letters of Interest, Proposals and Contracts.
2. During the selection phase:
   a. Final selection of prospective Contractors, Subcontractors and consultants.
   b. Establishing the work scope, schedules and budgets.
   c. Assisting in Contract negotiation.
   d. Drafting and finalizing the contract terms.
   e. Disseminating all proposal and contract information to the Project Manager and other appropriate Staff Members.
   f. Establishing proposal budgets and schedules and controlling the costs during the pre-contract stage.
3. During the implementation phase of the project:
   a. Monitoring the project performance and the financial status.
   b. Meetings with the project parties, as needed, to assess work progress and address any possible concerns.

2.1.3 Project Manager

The Project Manager is responsible for maintaining liaison with different parties, as well as overall responsibility for all technical and administrative aspects of the project. The Project Manager reports to the Project Officer and the Unit Manager, as required. The Project Manager has the authority to make modifications to the requirements of the QA Program in order to comply with the Owner's special requirements and to suit objectives of a particular job. The Project Manager will also determine which QA Procedures are to be followed and will modify those procedures as necessary to suit specific job requirements, all subject to the approval of the QA Manager. Specific duties of the Project Manager include the following:

1. Review the project scope, contract plans and specifications for construction related services.
2. Satisfy the organizational needs, equipment and manpower requirements to adequately implement required QA Program activities.
3. Implement and monitor the QA Program activities for the project.
4. Monitor compliance with the provisions of the contract.
5. Maintain the relation between the Owner and the Contractor.
6. Resolve errors and omissions on construction plans and specifications, and assist in the solution of technical problems.
7. Receive all project information and properly disseminate them to the appropriate staff members.
8. Approve reports, specifications and drawings.

2.1.4 Resident Engineer

Responsibilities of the Resident Engineer include the following:

1. Review construction plans and specifications and review the contract for construction related services.
2. Establish QA Program activities, responsibilities, and documentation requirements.
3. Implement and administer the day-to-day QA Program activities to verify conformance to the plans, specifications and the referenced quality standards. Expedite distribution of the QA Program documents and information.
4. Coordinate QA Program activities with the Project Manager, the Design Engineer, the Contractor and its Subcontractors. Receive and review staff comments on the quality of the work and take action as required. Advise the Project Manager of potential or existing quality problems.
5. Review and evaluate all required inspections, nonconformances and audit reports. Monitor that reports are

timely, accurate, distributed and reconciled. Address and resolve quality problems reported by the Construction Inspectors. Verify that Contractor's QC procedures and reporting systems are adequately established, accurate and current.

6. Assist the Project Manager in evaluating the staffing requirements and qualifications of project personnel. Verify individual qualifications.
7. Review technical information submitted by the Contractor to ensure conformance to the submittal requirements of the plans and specifications.
8. Direct all required inspections of the procured materials for incorporation in the project work. Monitor the quality certifications, proper quantities, and the required identifications. Monitor inspection for, and documentation of, any shipping and/or storage damages.
9. Review test reports of the materials to verify that the specified tests have been performed in the required number or frequency. Indicate conformance or non-conformance with the plans and specifications and referenced quality standards.
10. Instruct and train the Construction Inspectors in their particular duties pertaining to the current and upcoming project work.
11. Review and evaluate claims, requests for change orders and time extensions in accordance with the provisions of the plans and specifications. Make recommendations to the Project Manager for resolution of any contractual dispute.
12. Supervise all administrative services needed to document the construction process.
13. Report work progress, schedule, tests and contractual matters, as specified.

2.1.5 Office Engineer

Responsibilities of the Office Engineer include the following:

1. Develop and maintain the QA Program records system and the project-filing index in cooperation with the Resident Engineer. Monitor the activities of recording clerks.
2. Receive, file and distribute to designated recipients the QA Program, all documents produced by the Construction Inspectors, the Resident Engineer, testing laboratories and the Contractor.
3. Monitor and evaluate, under the direction of the Resident Engineer, the reporting of quality data.
4. Assist the Resident Engineer in monitoring the Contractor's QC programs. Verify implementation of Contractor's QC documentation at all levels of inspection.
5. Verify the quality documentation of furnished materials and equipment upon arrival at the construction site.
6. Review material test reports for adequacy, completeness, and conformance to specifications and the referenced quality standards.
7. Provide accurate reporting of all QA Program activities to verify compliance with the plans and specifications. Assist Construction Inspectors with the production of QA Program records.
8. Produce, or secure and maintain for use, a set of up-to-date "As-Built" or record drawings. Verify accuracy, current revisions, and reproducibility of "design" drawings and their certification. Verify the distribution of up-to-date contract documents to the field staff and the Contractor.
9. Verify that materials incorporated in the work are identified by dates, bulletin numbers, change order numbers, signatures and other pertinent data requirements.
10. Act, in the absence of the Resident Engineer, on matters concerning the QA Program for the project.
11. Maintain the QA Program files to provide identifiable, retrievable and reproducible construction documents; to include contract drawings, specifications and records of incorporated materials and equipment, tests and inspection data.

2.1.6 Construction Inspector(s)

Responsibilities of the Construction Inspector(s) include the following:

1. Maintain daily contact with the Resident Engineer and the Office Engineer, and assist in the implementation of the QA Program activities.
2. Perform daily visual on-site inspections of workmanship and materials. Document project activities, payment quantities and QA Program activities. Prepare Daily Inspector's Reports (DIR). Coordinate inspection activities with the inspections of the Contractor, the materials test laboratory technicians, and the Owner's representatives according to the scheduled QA Program activities.
3. Witness all required field-tests by the Contractor. Verify that the individual performing the test signs the test documentation. Construction Inspector to indicate that he/she witnessed the test where applicable, date the document, and indicate concurrence with the results.
4. Verify during preparatory inspection meetings with the Contractor representative(s) that contract-required engineering and quality-related documents have been submitted and approved, prior to commencing the work.
5. Advise the Resident Engineer of potential or existing quality problems.
6. Record tests witnessed and inspections performed on the DIR, and verify that the report is timely, accurate and signed.
7. Review material test reports to verify that the specified tests are performed in adequate number, and that the results

are in accordance with the contract plans, specifications, and the referenced quality standards.

8. Assist during receiving inspections of materials and equipment for proper quantity, identification of any shipping damage, and conformance with the procurement documents. Receive and file certificates of compliance, shipping documents and logs.
9. Maintain testing equipment in working order. Arrange for calibration of test equipment at required intervals. Document calibration of test equipment.
10. Verify that work in the field is performed in accordance with contract plans and specifications. Ensure that plan sets issued for construction are current.
11. Coordinate with or assist survey crews to verify correct locations, alignments and elevations of ongoing or completed work.

2.2 Preparation of a Project-Specific Quality Assurance Plan

2.2.1 Project Startup Considerations

An important QA element before starting a construction project is becoming fully familiar with the intent and details of the plans and specifications. Identifying any apparent errors, omissions or ambiguities early in the project will help insure quality, and will limit change orders and contractual disputes. The project startup duties for the project team include:

1. Review the contract for the performance of Construction Related Services and list those administrative, inspections, observation duties and procedures for which the Contractor is responsible. A sample of those duties, which the Contractor is solely responsible for, includes:
   a. Contractor's means and methods for construction.
   b. Safety of Contractor's work force.
   c. Contractor's adherence to schedule, etc.
2. Assisted by the Chief or Senior Construction Inspector, review the Construction Contract Documents (Plans and Specifications) between the Owner and the Contractor. List all administrative, procedural, inspection, and field testing responsibilities to be performed. At this stage, any discrepancies and ambiguities in the duties and responsibilities should be identified and resolved prior to proceeding with the project.
3. Understand the impact of any imposed environmental, phasing or operational limitations or constraints on the construction processes.
4. Review the proposed Project Staff and Organization for:
   a. Adequacy of staff positions needed to cover the contractual obligations.
   b. Required staff licensing and certification.
   c. Technical qualifications and experience of assigned personnel, Contractors and its Subcontractors for specialty services.
   d. Need for staff training in specific inspection procedures, safety awareness, and limitations in the authority, relations with the Contractor, its Subcontractors, the Owner, and the public.
5. Review the physical aspects of the project work area and adequacy of the facilities provided to house construction site staff.
6. Verify the availability of measuring and testing (M&T) equipment and instruments needed to verify the quality of components to be incorporated into the finished work. Check that licenses needed to own, store, or operate M&T equipment are on file. Determine which testing will be done in-house and which will be done by an independent facility.
7. Ensure availability of all forms needed to document the quality of the constructed project and its administrative processes.

2.2.2 Considerations Related to the Verification of Quality of the Constructed Project

Review the contract agreement for the specific obligations related to the following:

2.2.2.1 Document Control Establish procedures for issuance and transmission of design revisions and addenda to the plans and specifications, shop drawings, staging and phasing plans, traffic control plans, Contractor's required submissions of work plans, schedules and general correspondence.

2.2.2.2 Constructability Review Following are important items to consider during the constructability review:

1. Check for realistic scheduling of work activities. Identify need for overtime and double shift work and unusually high peak demand for machinery and construction plant.
2. Check the proposed construction schedule for compatibility with sequencing and phasing of the work, as related to natural phenomena, such as high flood periods, hurricane seasons, high tides and general inclement weather periods.
3. Check for proper sequencing of operations. Identify any operations that are on the critical path, and could cause delays and possible loss of a construction season.
4. Check for adequate rights-of-way and access to the construction areas. Verify adequacy of areas reserved for Contractor's work, lay down and storage areas.
5. Check for interference with traffic, utilities and other ongoing or sequential contract work by others.

6. Identify long-lead items and the need for unusual construction materials and equipment.
7. Check for use of appropriate materials and up-to-date designs and technology. Identify use of unconventional or highly specialized designs or expensive materials, which could limit competition and result in high bids. Verify that new materials are being used in the manner intended by the manufacturer.
8. Check contract documents for ambiguities and inconsistencies that could lead to schedule delays, contractual disputes and possible legal actions. Verify that details shown are adequate to assure proper erection and construction sequencing.
9. Check for community impacts such as noise, dust, and release of toxic or otherwise unsafe materials into the environment.
10. Check for conformance to all governmental regulations, which safeguard the environment, the work place and the public.
11. Check that accessibility for maintenance, repair and in-service inspection has been provided. Review maintenance, repair and inspection requirements and verify that the design shown on the drawing provides adequate access for these activities.
12. Avoid duplication of data in the specifications and the drawings, by ensuring that:
    a) Dimensions are correct and consistent, and tolerances are appropriate.
    b) Drafting practices conform to the standards specified.
    c) Drawings are legible.
    d) Drawings reproduce satisfactorily.

2.2.2.3 Quality Aspects of Construction Specifications Problems related to the specifications that may lead to change orders, claims, arbitration and litigation are broken down into the following categories in descending order of frequency:

"Or Equal" Specifications To avoid problems with "or equal" specifications it is best to list those physical or functional properties of the name brand product you wish to see duplicated in the "or equal" product.

Constructability Contract documents may be defective if the work shown is not reasonably constructible. Remember the ordinary sequence of trades in the construction process, and look for bad phasing or details that require a succeeding trade to install something before the preceding trade would normally arrive on the job.

In setting the tolerances, be sure that they follow industry standards or are no more stringent than contained in standard specifications. If more stringent tolerances are required, word the specifications so that the Contractor's attention is alerted to this fact, so that he/she can adjust his/her normal work methods and pricing to achieve the results required.

Overly strict or literal interpretation of the specifications on tolerances beyond the normal industry standards generally results in change order decisions in favor of the Contractor.

Ambiguities and Typographical Errors Ambiguities in the specifications are usually the result of duplication, which is to be avoided. If there are two ways of reasonably interpreting your documents the courts will usually side against the preparer. The use of standard specifications will help reduce this category of problems.

Conflicts between Plans and Specifications Specifications usually contain a clause in the general provisions establishing an order of precedence between the various contract document components. The usual order is:

1. Signed Contract
2. Other provisions such as special conditions
3. General provisions
4. Plans
5. Technical Specifications

To minimize conflicts between plans and specifications, it is important to avoid duplication. Avoid repeating the same information in plans and specifications. If an entire specifications section is in the plans, that section should be omitted entirely from the specifications. Construction contracts frequently contain a clause, which in effect says that anything mentioned in the specifications and not shown on the plans or shown on the plans and not mentioned in the specifications shall be interpreted as being shown or mentioned in both. The case of an item mentioned only in the specifications and not shown on the plans can lead to change orders on the basis that the Contractor had adequate information as to quality, but was unable to assess the cost of installing the item because its physical relation to other project components was not defined or was lacking. Leaving something out of the specifications that is shown on the plans leaves open the possibility for the Contractor to supply the cheapest possible alternative.

Inspection Requirements Overly restrictive tolerances have been discussed above. Inspection or observation of the Contractors' work invariably creates some interference with the performance of the work by the Contractor. Frequency of tests and observations should be in line with the normal industry standards or the standard specifications. Failure to adhere to the industry norms may produce claims. Overzealous or inconsistent inspection, although not part of this general subject, also is a frequent cause for change order claims in this category.

Safety and Health Requirements Failure to comply with local codes can result in lawsuits, charge-backs, or awards against the Design Engineer.

2.2.2.4 Product Identification, Traceability and Certification

1. Establish procedures for identifying materials and products, including documentation needed to verify the quality of products and materials, such as batch plant records, laboratory tests, catalog cuts and any other documentation.
2. Comply with storage requirements to prevent deterioration of materials and products at the work site including preventive maintenance while in storage.
3. Comply with requirements for identification, rejection, or segregation substandard or non-acceptable materials or products.
4. Comply with requirements for identification of certified materials—identification of the status of tests and inspections for incorporated materials, including specified marking, tagging, and stamping and/or physical isolation.

2.2.2.5 Process Control Comply with requirements in regard to specified construction processes.

2.2.2.6 Inspection and Testing The contract plans and specifications should be checked for any testing requirements, sampling frequency, acceptance criteria and tolerances. Easy checklists should be developed to assist the Construction Inspectors in assessing conformance to all testing requirements and to insure proper record keeping. Examples of checklists are provided in Section 2.2.7. Following are the steps required to develop QC procedures for testing and inspection:

1. Study the Plans and Specifications to identify all testing and inspection requirements for the project.
2. Assemble relevant contract documents needed to determine standards to be met for each test or inspection.
3. Develop any necessary checklists and train inspection staff.
4. Monitor for compliance to specified standards to be met according to the plans and specifications for:
   a. In-process tests and inspections
   b. In-plant tests and inspections
   c. Receiving inspections
   d. Final testing and inspections
5. Record results of required tests, inspections and observations in a timely manner on standard forms.

2.2.2.7 Maintenance of Measuring and Testing (M&T) Equipment

1. Establish a calibration and maintenance program for all M&T equipment used at the work site under the control of the field staff. Program may include specific contractual requirements, industrial or national standards and guidelines, or M&T equipment manufacturer's recommendations.
2. Document actions taken to calibrate and maintain testing equipment used and controlled by the worksite inspection staff.
3. Obtain acceptable calibration and maintenance documentation for testing Subcontractor's M&T equipment.

2.2.2.8 Certification of Tradesmen Monitor compliance for contractual requirements relating to the qualifications of tradesmen performing project work, such as specified licenses and certifications. Monitor for compliance with mandated training programs for the Contractor's staff.

2.2.2.9 Identification of Non-Conforming Work

1. Review for compliance with specified procedures for identification and documentation of non-conforming work.
2. Evaluate and resolve remedial actions according to the options allowed in the plans and specifications such as:
   a. Reworking to meet requirements;
   b. Acceptance of work with or without repair; and
   c. Use of materials or products at an alternative application or location.

2.2.2.10 Implementation of Corrective Actions Initiate and monitor corrective actions as governed by the applicable provisions of the plans and specifications:

1. Monitor corrective actions for effectiveness.
2. Pro-actively investigate causes for non-conformance and formulate remedial or alternative processes to prevent recurrences.
3. Implement and document process changes resulting from corrective actions.

2.2.3 Considerations Related to Performance and Administrative Services

Review the plans and specifications for specific obligations related to the following categories:

2.2.3.1. Claims and Change Orders

1. Implement specified procedures for handling and resolving claims, requests for extra compensation, time extensions and change orders.
2. Timely analysis of claims and change order requests, and formulation of clear and concise recommendations for their resolution.
3. Early identification of potential claims and their impact on project costs and schedule. Formulation of strategies for limiting claims.

2.2.3.2 Shop Drawings Implement specified procedures for the handling of shop drawings. Monitor and facilitate the timely review of these documents by the proper party, including documentation of the process.

2.2.3.3 As-Built or Record Plans Monitor the performance of contractual requirements for compiling and maintaining a current and updated Record Set of contract drawings and specifications. The Record Set may be compiled and produced by the Contractor or by the Owner's representative field staff, as contractually specified. Identify the reason for field changes in a separate record, and document any time or cost implications.

2.2.3.4 Coordination of Construction Activities

1. Schedule and conduct progress meetings, prepare agendas for meetings, and distribute Memorandums of Meetings to all attending parties. Identify issues requiring follow-up action. Designate the action party, and set time limits for the requested action. Monitor coordination of activities between the primary Contractor and its Subcontractor(s).
2. Review of Contractor's work schedule. Identify any schedule slippage and review remedial actions proposed by Contractor to meet the approved schedule.
3. Monitor coordination between the Contractor and its Subcontractors and impacted agencies, companies and jurisdictions.

2.2.4 Record Keeping Considerations

Sufficient documentation and records shall be accumulated to provide objective evidence that the construction process was performed in accordance with accepted engineering practice, as well as in conformance to contractual requirements. The documentation should include not only the final design documents, such as drawings and specifications, but also all construction records and any communications, instructions and directives that have a direct bearing on the project.

A record keeping system should be established prior to starting the project. The system as a minimum should be capable of:

1. Organize project files according to a mandated file index system or one developed for the particular project. Maintain the filing system to permit the timely and accurate retrieval of documents.
2. Establish and maintain separate files for documents to indicate the compliance with the QC system for the project. Records that document adherence to the provisions of the plans and specifications include:
   a. Inspection logs, Daily Inspector's Reports and diaries
   b. Test data, including mill tests and certifications
   c. Qualification reports
   d. Validation and calibration reports
   e. Material review reports
   f. Batch plant records
3. Prepare correspondence on a timely basis. Log incoming and outgoing correspondence. Log general complaints from the public and document environmental issues arising from the general public and governmental agencies. Log pending or follow-up correspondence.
4. Identify the receiving organization for project records and files at completion of project. Establish retention time for project files to be retained.
5. Maintain at the work site required publications, documents and other materials referred to in the plans and specifications needed to properly understand and carry out the work scope, and to comply with the requirements of the Owner, and of those of regulatory entities and standard-setting associations.

2.2.4.1 Retention of Records Reports and records to be retained shall be determined by the Project Manager and/or the Department Managers. Records designated for retention shall be legible, suitable for reproduction, complete and adequately identifiable to the item involved.

2.2.4.2 Subcontractors Records Records of Subcontractors shall be controlled and retained in the same manner as records of the Contractor.

2.2.4.3 Permanent Storage of Records Permanent documents designated for storage shall be stored in the Project file.

2.2.4.4 QA/QC Records A single file identified as "QA/QC Records" containing copies of all QA/QC documents shall be maintained in the project files.

2.2.5 Elements of a Project-Specific QA Plan

In the absence of a Owner-directed format and content requirement the following format and content is suggested:

Section 1 *Organizations for Quality*—Provide an organization chart and description of the quality process—who implements it, who monitors it and who has the ultimate responsibility.

Section 2 *Quality Review*—Identify the internal Unit Level reviewer delegated to conduct primary QA reviews, the schedule for such reviews, and the format of the reviews.

- The suggested format of the review is a brief summary memorandum outlining the highlights of the review and any recommended corrective actions to be taken. The completed checklists are to be appended to the summary review memorandum. The recipients (distribution) of the Quality Assurance Reviews shall be listed.
- Define the implementations of corrective actions to be taken and the required documentation needed to close out all listed corrective actions.

Section 3 *QA Records*—Define how the Project QA Reviews and documentation of any completed remedial actions shall be maintained as a permanent part of the project files. Specify that additional copies shall be filed with the Unit's Construction Service Coordinator together with the minimum retention period after project close out.

2.2.6 Preparation of Project-Specific QA Checklists

After the project-specific responsibilities and duties have been identified, they can be subdivided into the following broad categories:

1. Staffing and Staff Qualifications
2. Contract documents
3. Project Files
4. Project Start-up Requirements
5. Miscellaneous contractual Requirements
6. Claims and Change Orders
7. Schedule Monitoring
8. Estimates and Payments
9. Construction Close-Out
10. Daily Inspection Reports
11. Materials and Materials Certification: General
12. Materials and Materials Certification: Concrete

For each of the first 12 subdivisions, a pro-forma Quality Assurance Program (QAP) checklist has been prepared listing those concerns generally of relevance in assessing the quality of services the Contractor is providing.

The Resident Engineer and the chief or senior Construction Inspector in conjunction must review these draft QAP checklists with the Contract documents for the Construction Related Services. Any additional specific responsibilities imposed on the Contractor in these contract documents should be added to the draft QAP checklist items listed, under the appropriate subdivision. Blank spaces have been provided on each subdivision to "customize" or adapt the draft QAP checklist to the demands of the specific project. Add additional sheets, as needed.

The draft Checklists for Materials and Materials Certification, in particular, are very general and are limited to just a few of the standard technical construction specifications divisions. These Checklists must also be augmented with the quality requirements for those materials in the project's particular contract specifications. Additional checklists should be prepared for each of the major specifications divisions which are part of the particular contract and which require staff involvement in certifying, observing, inspecting, testing or assessment of results.

To allow further flexibility in the arrangement of checklists, the Resident engineer may wish to reorganize the checklists in accordance with the applicable paragraphs of the General and Special Provisions of his/her particular job.

Some Owners, mostly state DOTs, require their Construction Services providers to formulate their own Quality Assurance Plan. Such QA Plans are based on specific guidelines required by the Owner and are generally similar to the QAP checklists that follow.

2.2.7 QA Checklists for FRP Construction

A comprehensive QA and QC program implemented and monitored by the FRP material suppliers and the FRP installation Contractors should be maintained in order to insure quality repair. The QC is the direct responsibility of the Contractor and should cover all aspects of the strengthening project depending on the size and complexity of the project at hand. The quality assurance during construction is the responsibility of the Owner and can be achieved through a set of inspections, measurements, and applicable tests as specified in the construction specifications. The QAP checklists provided in this section address the most important parameters in the application of FRP systems. These checklists are offered as examples and are designed to assist the Owners in developing their QA requirements. They follow the Construction Specifications for Bonded Repair and Retrofit of Concrete Structures using FRP Composites, and

2.2.7.1 Project Start Up Requirements (QAP 1 to 6) Prior to starting the construction all Contractor shop drawings should be reviewed in light of the design plans and specifications to insure adherence to the contract documents. Any perceived conflicts should be resolved prior to starting the work. The Contractor should submit a material certification and identification of all the FRP materials to be used. The quantity, location and orientation of all FRP reinforcing materials to be used should be specified. The Owner should check if the Project is adequately staffed based on the complexity of the job and the approved construction schedule. The qualification of Contractor Personnel should be evaluated to insure that they meet the skills, ability and experience necessary for FRP strengthening projects.

2.2.7.2 Material Qualification and Acceptance (QAP 7) The FRP materials should be qualified on the basis of the plans and performance specifications requirements. The Contractor should provide information demonstrating that the proposed FRP material meets all design and specifications requirements such as tensile strength and modulus, durability, bond strength, and glass transition temperature. Performance tests on the supplied materials should be performed according to the QC test plan and should meet the requirements specified in the Engineer's performance specifications. These tests may include measuring parameters such as the tensile strength and modulus, glass transition temperature, gel time, pot life, as well as the adhesive shear strength. The results from independent tests of the FRP constituent materials and laminates fabricated with them should be submitted by the Contractor for approval prior to starting the work. Material property information supplied by the manufacturer or material supplier could form basis for acceptance of the FRP materials if no testing requirements are stated in the construction specifications.

2.2.7.3 Removal of Defective Concrete and Restoration of Concrete (QAP 8) The work under this section consists of restoring delaminated, or otherwise deteriorated, concrete on selected elements using polymer/latex modified concrete. Concrete restoration shall include the removal of all delaminated concrete from the area to be restored and an additional one to two inches from behind the reinforcement in delaminated areas. Any loose concrete remaining in the damaged region must be removed, leaving the member with sound concrete. Surfaces where the CFRP system is to be applied must be sound. Concrete spalls and delaminations must be repaired according to the procedure identified in the Plans and Specifications.

2.2.7.4 Inspection of Concrete Substrate (QAP 9) The concrete surface should be inspected before the application of the FRP material. The surface should be prepared in accordance with Engineer's specifications. The concrete surface should be examined for surface smoothness or roughness, holes, cracks, corners, and other imperfections.

2.2.7.5 Application Conditions (QAP 10) The ambient temperature, concrete surface, surface dryness should conform the Engineer's specifications. FRP application should be halted if rain appears to be imminent. If rain is threatening after starting the application process, the Contractor should be instructed to protect the installed areas against contact with surface moisture

2.2.7.6 FRP Application Process (QAP 11 to 13) Special care shall be taken to keep all records on the quantity of mixed resin during a one-day period, the date and time of mixing, the mixture proportions and identification of all components, the ambient temperature, the humidity, and other factors affecting the resin properties. These records shall also identify the FRP sheet used each day, its location on the structure, the ply count and direction of application, and all other useful information. Sample FRP plate specimens shall be fabricated according to a predetermined sampling plan, under the same ambient conditions and procedures used to apply the FRP material to the concrete surfaces. Performance tests on these FRP specimens may be conducted as needed. The evaluation of the relative cure of FRP materials can be performed by means of laboratory testing of sample plate specimens or resin samples using ASTM Standard D3418, or at the construction site, by physical observation of resin tackiness and hardness of work surfaces or retained resin samples. Visual inspection of fibre orientation and waviness may be required for specific FRP material systems since poor orientation infers misalignment of the entire system from the angles specified in the drawings. Fibre misalignments of more than 5° from the specified angle ($1/12$ slope) may adversely affect the provisional performance of the FRP reinforcement and should be reported to the Engineer. Non-compaction of fiber sheets when multiple plies are applied can result in significant voids, sagging and local areas of debonding, all of which will substantially effect the overall performance of the FRP system, and should be reported to the Engineer. Additional information is provided for pre-cured and near-surface mounted FRP systems.

2.2.7.7 Identification of Defective Work (QAP14) The inspection program should cover such aspects as the presence and extent of delaminations, the cure of the installed system, adhesion, laminate thickness, fibre alignment and material properties.

2.2.7.8 Post-Application—Quality Control Tests (QAP15) An inspection of the FRP repair system should be conducted after the full cure. Delaminations if detected should be evaluated considering their size and number relative to the overall application area, as well as their location with respect to structural load transfer. The inspection methods may include visual assessment acoustic sounding (hammer sounding), ultrasonics, thermography. Tension adhesion testing of cored samples should be conducted using known methods such as those described in ACI 503R or ASTM D4541. The sampling frequency should conform to the Engineer's specifications. Cored samples required for adhesion testing can also be used to determine the laminate thickness or number of plies. Approved methods to repair FRP materials having some delaminations may be used depending upon the size, the number of delaminations and their locations. These repairs should be performed in accordance to the Engineer's specifications. The laminate should then be re-inspected following delamination repairs, and the resulting delamination maps or scan compared with that of the initial inspection to verify whether the repair was properly accomplished. All inspection records and test results related to the FRP material should be retained. It should include delamination/repair, on-site bond tests, anomalies and correction reports as well as all mechanical/physical test results from the designated laboratories.

2.2.7.9 General Job Administration (QAP 16 to 20) QAP 14 to 18 address general job administration conditions such us claims and change, orders, schedule monitoring, estimates and payments and daily inspectors reports (DIR).

The following checklists are pro-forma and must be modified to the particular project.

FORM No. QAP 1
Project Start up Requirements

Project No: ________________ Project Name: ______________________________________

YES	NO	N/A	
____	____	____	1. Have the Construction Contract Documents been preliminarily reviewed for their overall completeness, obvious errors and omissions, constructability, etc.?
____	____	____	a. Have the provisions been reviewed with the field staff?
____	____	____	b. Have the Design Engineer and the Owner been advised of findings?
____	____	____	2. Have the Contract Documents for Construction Related Services between the Consultant and the Owner been reviewed against the Construction Contract Documents to identify possible conflicts in imposed duties and responsibilities?
____	____	____	a. Have all perceived conflicts been resolved?
____	____	____	3. Has a pre-construction meeting been held?
____	____	____	a. Is the agenda for the pre-construction meeting in accordance with the Owner's requirements?
____	____	____	b. Are minutes of the meeting in the files?
____	____	____	4. Has Contractor submitted all required documents on time:
____	____	____	Insurance certificates?
____	____	____	Bonds?
____	____	____	Construction Inspector qualifications?
____	____	____	Permits?
____	____	____	Equipment calibration?
____	____	____	Quality Control Plans?
____	____	____	Material Safety Data Sheets?
____	____	____	Schedules?
____	____	____	Certificate(s)?
____	____	____	5. Have accident and emergency reporting procedures and documentation been established and reviewed with the field staff?
____	____	____	6. Are all forms needed to document the construction processes and quality of the work on hand at the start of the project?
____	____	____	7. Is the project fully equipped with necessary field measuring and testing (M&T) equipment?
____	____	____	8. Is the measuring and testing (M&T) equipment periodically re-calibrated according to the manufacturers recommendation?
____	____	____	9. Are calibration documents on file?

Remarks:
____
____
____

Reviewer/Date: ______________________________
Resident Engineer/Date: ______________________________

FORM NO. QAP 2
Contract Documents

Project No: __________________ Project Name: ____

YES	NO	N/A	
_____	_____	_____	1. Is a complete set of contract documents available?
_____	_____	_____	a. Plans?
_____	_____	_____	b. Specifications?
_____	_____	_____	c. Other?
_____	_____	_____	2. Are all design changes and amendments incorporated in these documents?
_____	_____	_____	3. Are all field changes incorporated in the documents?
_____	_____	_____	4. Are "As-Built" plans being updated to reflect field revisions?
_____	_____	_____	5. Have all design and field changes been signed and sealed by the Design Engineer?
_____	_____	_____	6. Have all design and field changes been included and approved in the Change Orders?
_____	_____	_____	7. Are shop drawings being logged and tracked?
_____	_____	_____	8. Are all support documents required or referenced in the CE&I contract available on site?

Remarks:

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Reviewer/Date: ____________________________________

Resident Engineer/Date: ____________________________________

FORM NO. QAP 3
Specifications Review Checklist

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Is the specifications complete and clear to the extent necessary to properly specify construction and performance requirements?
_____	_____	_____	2.	Have duplications or inconsistencies between contract drawings and the specifications been eliminated?
_____	_____	_____	3.	Are proper codes, standards, processes, etc. referenced?
_____	_____	_____	4.	Are requirements for shop drawings properly specified, both as to content and timely submission?
_____	_____	_____	5.	Are new materials employed and installed in the manner approved by the manufacturer?
_____	_____	_____	6.	Is proper test and inspection documentation specified?
_____	_____	_____	7.	Are the acceptance criteria tests (tolerances, etc.) specified, and are they adequate, realistic, and in line with the ordinary construction practice?
_____	_____	_____	8.	Are provisions made for the qualification and approval of special construction processes and for the personnel performing these processes?
_____	_____	_____	9.	Are measuring and test equipment calibration requirements and cleaning, storage and handling requirements properly specified?
_____	_____	_____	10.	Are measurement units and basis of payment properly specified?
_____	_____	_____	11.	Is nomenclature used in the specifications exactly as used on the contract drawings?

Remarks:

Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 4
Drawing Review Checklist

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Is the scope of the set of contract drawings satisfactory?
_____	_____	_____	2.	Do the structures, equipment or components satisfactorily meet the functional needs and requirements?
_____	_____	_____	3.	Has accessibility for maintenance, repair and in-service inspection been provided?
_____	_____	_____	4.	Are materials properly identified on the contract drawings?
_____	_____	_____	5.	Are the items constructible as shown? Has the normal sequencing of construction trades been followed?
_____	_____	_____	6.	Is construction phasing or staging clearly shown?
_____	_____	_____	7.	Are dimensions and tolerances correct and consistent?
_____	_____	_____	8.	Have duplications and redundancy of information, data and dimensioning been eliminated?
_____	_____	_____	9.	Are the Plans signed and sealed by a Professional Engineer?
_____	_____	_____	10.	Are the drawings legible and reproducible?
_____	_____	_____	11.	Do the titles and drawing numbers agree with the cover sheet list of the drawings?

Remarks:

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Reviewer/Date: ______________________________________

Resident Engineer/Date: ______________________________________

FORM NO. QAP 5
Staffing and Staff Qualification

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Is the Project adequately staffed based on its complexity and the approved construction schedule?
_____	_____	_____	2.	Are project personnel on the job site during Contractors operations?
_____	_____	_____	3.	Are the staff members properly trained and informed regarding:
_____	_____	_____		a. Authority, responsibilities and duties of the Construction Inspector.
_____	_____	_____		b. General rules of project safety.
_____	_____	_____		c. Hazard Communication Employee Training Program.
_____	_____	_____		d. Specific technical inspection and testing requirements.
_____	_____	_____		e. Emergency and Accident procedures.
_____	_____	_____	4.	Are the names and qualifications of the Contractor staff on file?
_____	_____	_____	5.	Do Contractor staff members have required professional or technical accreditation?
_____	_____	_____		a. Has this been verified?
_____	_____	_____	6.	Does the Contractor's staff include a qualified provider of First Aid services?

Remarks:

____

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____

Reviewer/Date: ______________________________

Resident Engineer/Date: ______________________________

FORM NO. QAP 6
Miscellaneous Contractual Provisions

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Is a copy of the fully executed Bid Blank in the Prime Contractors file?
_____	_____	_____	2.	Is there an EEO compliance checklist on file?
_____	_____	_____	3.	Have the Contractor's EEO Policy, Affirmative Action and DBE Affirmative Action Plans been submitted?
_____	_____	_____	4.	Have the monthly EEO reports been filed?
_____	_____	_____	5.	Have all needed permits been applied for by the Owner?
_____	_____	_____		a. By the Contractor?
_____	_____	_____		b. Are copies of all required permits in the files?
_____	_____	_____		c. Are the conditions of each permit being adhered to?
_____	_____	_____	6.	Are environmental permits or environmental control plans required? If yes, are they included in the submittal package?
_____	_____	_____	7.	Has a Traffic Control Plan been specified for this project?
_____	_____	_____	8.	Have local law enforcement agencies been notified by the Contractor of the provisions of the Traffic Control Plan?
_____	_____	_____	9.	Has the Contractor submitted names and telephone numbers of the emergency contact personnel to all agencies involved?
_____	_____	_____	10.	Has the Contractor submitted evidence of required bonding and insurance?
_____	_____	_____	11.	Are meetings with the Owner on a scheduled basis?

Remarks:

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Reviewer/Date: ________________________________

Resident Engineer/Date: ________________________________

FORM NO. QAP 7
Material Qualification and Acceptance

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Have all required samples been collected and submitted?
_____	_____	_____	2.	Are all certified mill analyses and third-party test results on file?
_____	_____	_____	3.	Are all material acceptance requirements being met?
_____	_____	_____	4.	Are the materials that have failed testing requirements disposed of according to the contract requirements?
_____	_____	_____	5.	Are "or equal" materials and equipment submitted by the Contractor approved by the Design Engineer?
_____	_____	_____	6.	Are all certified materials properly identified according to the contract requirements?
_____	_____	_____	7.	Have all relevant documents that are needed to determine if the standards are met provided to the inspection staff?

Remarks:

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Reviewer/Date: ____________________________________

Resident Engineer/Date: ____________________________________

FORM NO. QAP 8
Removal of Defective Concrete and Restoration of Concrete

Project No: __________________ Project Name: ____

YES	NO	N/A	
_____	_____	_____	1. Have the perimeters of existing spalls been identified and sawcut to a minimum depth of 3/4 of an inch to prevent feathered edges?
_____	_____	_____	2. Are the limits of concrete removal for each member identified in the plans?
_____	_____	_____	a) If yes, did the Contractor remove any concrete beyond the identified areas?
_____	_____	_____	b) Did the Contractor obtain the Engineer approval to remove concrete beyond the identified areas?
_____	_____	_____	3. Are Cracks within solid concrete greater than 0.01 in. (0.25mm) and spaced closer than 1.5 in. (38 mm) or Cracks wider than 1/32 in. (0.8 mm) have been epoxy injected?
_____	_____	_____	4. After removal of all defective areas, did the Contractor inspect and clean the substrate from any dust, laitance, grease, oil, curing compounds, wax, impregnations, foreign particles and other bond inhibiting materials?
_____	_____	_____	5. Has all exposed steel been sandblasted clean near white appearance prior to concrete placement?
_____	_____	_____	6. Was Mechanical anchorage of the repair material with the substrate specified?
_____	_____	_____	a) If yes, were they installed according to Specifications?
_____	_____	_____	7. Did the Contractor apply a bonding and reinforcement protection to all exposed reinforcement and concrete surface prior to concrete placement?
_____	_____	_____	8. Did the Contractor use the approved material and method of application including manufacture's technical specifications and formulation if applicable?

Remarks:

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Reviewer/Date: ________________________________

Resident Engineer/Date: ________________________________

FORM NO. QAP 9

Inspection - Surface Preparation

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Is the restored concrete surface smooth, uniform and matching the concrete component's original profile? a) If No, were the deviations less than 1/32 in. (0.8 mm)?
_____	_____	_____	2.	Did the Contractor remove form lines and sharp edges by grinding or filling with putty?
_____	_____	_____	3.	Have all inside and outside corners and sharp edges been rounded or chamfered to a minimum radius of 1 in. (25 mm)?
_____	_____	_____	4.	Are there any voids with diameters larger than 1/2 in. (12.7 mm) and depressions greater than 1/16 in. (1.6 mm), when measured from a 12 in. (305 mm) straight edge placed on the surface?
_____	_____	_____		a) If yes, have surface depressions and voids been filled and cured according to Specifications?
_____	_____	_____	5.	Have all Cracks in the surface of concrete or the substrate wider than 0.01 in. (0.25 mm) and spaced closer than 1.5 in. (38 mm) or Cracks wider than 1/32 in. (0.8 mm) been filled using pressure injection of epoxy in accordance with the procedures outlined in Specifications?
_____	_____	_____		a) Was any surface roughness resulting from crack injection alleviated according to Specifications?
_____	_____	_____	6.	Was the surface checked and cleaned of any dust, laitance, grease, oil, curing compounds, wax, impregnations, surface lubricants, paint coatings, stains, foreign particles, weathered layers and any other bond inhibiting materials?
_____	_____	_____	7.	Was the final preparation of the all surfaces receiving FRP performed according to the Specifications?

Remarks:

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Reviewer/Date: ______________________________

Resident Engineer/Date: ______________________________

FORM NO. QAP 10

Application Conditions

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Is the ambient temperature and temperature of concrete surface within the range of 50°F-90°F, or as specified by the manufacturer?
_____	_____	_____	2.	Are the contact surfaces completely dry at the time of installation of FRP system?
_____	_____	_____		a) Was the moisture level measured using a mortar moisture meter?
_____	_____	_____		b) Was the moisture level less than 4.3% or the specified limit?
_____	_____	_____	3.	Is relative humidity level in the range of 65% - 82%?
_____	_____	_____	4.	Does the rain appear to be imminent?
_____	_____	_____		a) If yes, stop application of the material until dry conditions are assured.
_____	_____	_____	5.	If rain is threatening after starting the application process, instruct the Contractor to protect the installed areas against contact with surface moisture.

Remarks:

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Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 11

FRP Application Process (Wet Lay-Up Systems)

Project No: __________________ Project Name: ____

YES	NO	N/A	
			1. *Resin Mix*
______	______	______	- Is the resin prepared according to the mix ratio and procedures recommended by the manufacturer until thorough mixing with uniform color and consistency is achieved?
______	______	______	- Is the resin diluted with organic solvents? (NOT allowed)
______	______	______	- Is the resin mixed in quantities sufficiently small to ensure its use within manufacturer recommended pot life?
______	______	______	- Is the excess resin disposed of when exceeded its pot life, or began to generate heat or show signs of increased viscosity?
			2. *Primer and Putty*
______	______	______	- Is the primer applied uniformly to penetrate all surface pores of concrete substrate where the FRP system is to be installed?
______	______	______	- Does the rate of application of primer follow the manufacturer's recommendations?
______	______	______	- Are the ambient and concrete surface temperatures as specified in the contract drawings and recommended by the manufacturer?
______	______	______	- Is the excess primer disposed of when exceeded its pot life?
______	______	______	- Is the putty, if necessary, applied as soon as the primer becomes tack-free or until non-sticky to the fingers?
______	______	______	- In case of delays longer than 7 days, is the surface of primer cleaned and prepared for the putty, if necessary?
______	______	______	- Does the applied putty meet the surface profile according to the contract drawings?
______	______	______	- Is the excess putty, if used, disposed of when exceeded its pot life?
______	______	______	- Are the surfaces of primer and putty protected from dust, moisture and other contaminants before applying the FRP system?
			3. *Fabric Saturation and Placement*
______	______	______	- Is the saturant applied uniformly on all surface areas of concrete where the FRP system is to be installed?
______	______	______	- Is the viscosity of the saturant sufficiently low, according to the manufacturer recommendations, to fully impregnate the fiber sheets?
______	______	______	- Does the rate of application of saturant follow the manufacturer recommendations?
______	______	______	- Are the ambient and concrete surface temperatures as specified in the contract drawings and recommended by the manufacturer?
______	______	______	- Is the excess saturant disposed of when exceeded its pot life?
______	______	______	- Is the fiber sheet cut to the length specified in the contract drawings (typically in segments shorter than 15 to 20 ft (4.6 to 6.1 m))?
______	______	______	- Is the fiber sheet placed properly and pressed gently onto the wet saturant within its pot life?
______	______	______	- Is any entrapped air between fiber sheet and concrete released?
______	______	______	- Is rolling in the fiber direction for unidirectional fiber sheets?

YES	NO	N/A	
______	______	______	- Is rolling in the fill direction end to end, and then the warp direction, for bi-directional fiber sheets?
______	______	______	- Is there excessive force or sharp metal rollers involved that could damage the fibers? (NOT allowed)
______	______	______	- Is sufficient saturant applied on top of the fiber sheet as overcoat to fully saturate the fibers?
______	______	______	- Is there any interruption in the application of undercoat, fiber sheets, and overcoat?
______	______	______	- Is the above sequence repeated properly for each additional fiber sheet, with an overcoat resin 15%-20% greater than a single ply?
______	______	______	- Is each new fiber sheet applied before the onset of complete gelation of the previous layer?
______	______	______	- Does the number of plies applied in a single day follow the contract drawings and the manufacturer recommendations?
______	______	______	- In case of several days of delay between plies, is the surface of previously cured layers of the FRP system prepared properly before applying new fiber sheets?
			4. *Splice and Overlap*
______	______	______	- Are lap joints constructed when there is an interruption in the direction of the fibers?
______	______	______	- Are lap splice lengths as specified in the contract drawings, but at least 6 in. (152 mm)?
______	______	______	- Are lap splices staggered on multiple plies and adjacent strips, unless permitted in the contract drawings?
______	______	______	- Are all lap joints in the fiber directions made in a single day?
______	______	______	- Is there any lap joint in the transverse direction, if specified in the contract drawings?
			5. *Fiber Orientation*
______	______	______	- Are the fibers aligned on the structural member according to the contract drawings?
______	______	______	- Is there any deviation in fiber alignment more than 5°? (NOT allowed)
______	______	______	- Are fibers free of kink, folds and waviness?
			6. *Anchoring of FRP Sheets*
______	______	______	- Is anchorage for the FRP sheets installed according to the contract drawings, and in such a way to avoid damage to fibers or concrete?
			7. *Stressing Applications*
______	______	______	- Are stressing hardware and procedures according to the contract drawings and the manufacturer recommendations?
______	______	______	- Does the grouting pressure according to the contract drawings?
			8. *Curing and Final Coating*
______	______	______	- Is the FRP system allowed to cure according to contract drawings and the manufacturer recommendations?
______	______	______	- Is the resin chemistry field modified for rapid curing? (NOT allowed)
______	______	______	- Is elevated temperature used for curing follows the contract drawings and manufacturer recommendations?
______	______	______	- Is the FRP system protected until it is fully cured?
______	______	______	- Is the FRP system under full load before it is fully cured?
______	______	______	- Is continuous pressure applied, if necessary, for the cure of FRP system?

YES	NO	N/A	
______	______	______	- Is the surface of FRP system prepared according to the contract drawings and the manufacturer recommendation to receive coating?
______	______	______	- Are solvent wipes used for surface cleaning? (NOT allowed)
______	______	______	- If abrasive cleaning is necessary, is the air pressure at the nozzle limited to avoid any damage to fibers?
______	______	______	- Is the thickness of protective coating for the FRP system as specified in the contract drawings and specifications?
______	______	______	- Does the final appearance match the color and texture of the adjacent concrete?

Remarks:

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Reviewer/Date: ________________________________

Resident Engineer/Date: ________________________________

FORM NO. QAP 12

FRP Application Process (Pre-Cured Systems)

Project No: __________________ Project Name: ____

YES	NO	N/A	
			1. *Application of Adhesives*
______	______	______	- Is the adhesive prepared according to the mix ratio and procedures recommended by the manufacturer until thorough mixing with uniform color and consistency is achieved?
______	______	______	- Is the adhesive applied uniformly on all surface areas of concrete substrate where the pre-cured FRP system is to be applied?
______	______	______	- Does the rate of application of adhesive follow the manufacturer's recommendations?
______	______	______	- Are thickness and viscosity of the adhesive layer according to the manufacturer's recommendations?
______	______	______	- Are the ambient and concrete surface temperatures as specified in the contract drawings and recommended by the manufacturer?
______	______	______	- Is excess resin that has exceeded its pot life disposed of?
			2. *Placement of Pre-Cured System*
______	______	______	- Is the pre-cured FRP system clean?
______	______	______	- Is the pre-cured FRP system cut to the length specified in the contract drawings?
______	______	______	- Are manufacturer's recommendations on the timing and sequence of stacking, overlap and banding, horizontal and vertical joints, staggering of splices and overlap and butt joints followed?
______	______	______	- Is the pre-cured FRP system placed in the wet adhesive within its pot life?
______	______	______	- Is entrapped air between laminate and concrete released?
______	______	______	- Is excess adhesive between laminate and concrete removed?
______	______	______	- Is the FRP system left undisturbed until the adhesive fully cures?
			3. *Anchoring of Pre-Cured System*
______	______	______	- Are permanent anchorage for the FRP system properly installed according to the contract drawings?
______	______	______	- Are temporary clamping and shoring for the FRP system properly installed according to the contract drawings?
			4. *Grouting of Pre-Cured Shells*
______	______	______	- Is the pre-cured FRP shell around concrete column grouted at least 24 hours after installation?
______	______	______	- Does pressure grouting follow the contract drawings and the manufacturer recommendations?
______	______	______	- Does the grout have a shrinkage strain of less than 0.0005 and a compressive strength greater than 4,000 psi (27.6 MPa)?
			5. *Stressing Applications*
______	______	______	- Are stressing hardware according to the contract drawings and the manufacturer recommendations?
______	______	______	- Are the stressing procedures followed according to the contract drawings and the manufacturer recommendations?

YES	NO	N/A	6. *Curing and Final Coating*
_____	_____	_____	- Is the FRP system allowed to cure according to contract drawings and the manufacturer recommendations?
_____	_____	_____	- Is the resin chemistry field modified for rapid curing? (NOT allowed)
_____	_____	_____	- Is elevated temperature used for curing follows the contract drawings and manufacturer recommendations?
_____	_____	_____	- Is the FRP system protected until it is fully cured?
_____	_____	_____	- Is the FRP system under full load before it is fully cured?
_____	_____	_____	- Is continuous pressure applied, if necessary, for the cure of FRP system?
_____	_____	_____	- Is the surface of FRP system prepared according to the contract drawings and the manufacturer recommendation to receive coating?
_____	_____	_____	- Are solvent wipes used for surface cleaning? (NOT allowed)
_____	_____	_____	- If abrasive cleaning is necessary, is the air pressure at the nozzle limited to avoid any damage to fibers?
_____	_____	_____	- Is the thickness of protective coating for the FRP system as specified in the contract drawings and specifications?
_____	_____	_____	- Does the final appearance match the color and texture of the adjacent concrete?

Remarks:

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Reviewer/Date: ______________________________

Resident Engineer/Date: ______________________________

FORM NO. QAP 13

FRP Application Process (Near-Surface Mounted Systems)

Project No: ________________ Project Name: ____________________________________

YES	NO	N/A	
			1. *Application of Embedding Paste*
______	______	______	- Is the embedding paste prepared according to the mix ratio and procedures recommended by the manufacturer until thorough mixing with uniform color and consistency is achieved?
______	______	______	- Are all grooves, where the FRP system is to be placed, half filled with the paste?
______	______	______	- Are voids between concrete substrate and the embedding paste removed?
______	______	______	- Are the ambient and concrete surface temperatures as specified in the contract drawings and recommended by the manufacturer?
______	______	______	- Is the excess paste disposed of when exceeded its pot life?
			2. *Placing FRP Reinforcement*
______	______	______	- Is the FRP bar or strip clean?
______	______	______	- Is the FRP bar or strip cut to the length specified by contract drawings?
______	______	______	- Is there any shearing of FRP bar or strip? (NOT allowed)
______	______	______	- Is the FRP bar or strip placed at mid-depth of the groove and lightly pressed to force the paste to flow around it?
______	______	______	- Is the grove fully filled with additional paste and then leveled?

Remarks:

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Reviewer/Date: ______________________________

Resident Engineer/Date: ______________________________

FORM NO. QAP 14

Identification of Defective Work

Project No: ___________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Did you find any voids and air encapsulation between the concrete and the layers of primer, resin and/or adhesive, and within the composite itself?
_____	_____	_____	2.	Are there any delaminations between layers of composite fabric?
_____	_____	_____	3.	Are there any broken or damaged edges of the composite?
_____	_____	_____	4.	Is there any wrinkling and buckling of fiber and fiber tows?
_____	_____	_____	5.	Are there any discontinuities due to fracture of fibers, breaks in the fabric, or cracks in prefabricated material?
_____	_____	_____	6.	Are there any cracks, blisters or peeling of the surface coating?
_____	_____	_____	7.	Are there any resin starved areas or areas with non-uniform impregnation/wet-out?
_____	_____	_____	8.	Are there any under cured or incompletely cured polymer?
_____	_____	_____	9.	Are there any incorrectly placed reinforcement configurations?

Remarks:

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Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 15

Post-Application - Quality Control Tests

Project No: ______________ Project Name: ______________________________

YES	NO	N/A	
____	____	____	**1. Inspection for Debonding** Perform surface inspection for any swelling, bubbles, voids or delaminations after at least 24 hours for initial resin cure.
____	____	____	Is the presence of voids and air pockets suspected? If yes, - Perform an acoustic tap test with a hard object to identify delaminated areas by sound. - Mark all voids and assess them in term of size. - Repair Voids in accordance to the procedures established in the contract drawings and specifications.
____	____	____	**2. Inspection for Adhesion** Perform direct pull-off test according to ASTM D4541 or ACI 503R-93 after at least 24 hours for initial resin cure.
____	____	____	Are test locations representatives and on flat surfaces?
____	____	____	Are the number of tests performed in accordance to the number established in the contract drawings and specifications?
____	____	____	Is the observed failure mode of the core specimen cohesive within concrete? Failure at the bond line at tensile stress below 200 psi (1.38 MPa) is unacceptable.
____	____	____	Repair concrete area after bonding test according to the procedures established in the contract drawings and specifications.

Remarks:

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Reviewer/Date: ______________________________

Resident Engineer/Date: ______________________________

FORM NO. QAP 16

Claims and Change Orders

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Have any claims been made to date?
_____	_____	_____	2.	Has the Contractor provided written notification of all claims?
_____	_____	_____	3.	Did the notifications include specifics of the claims?
_____	_____	_____	4.	Did the Resident Engineer acknowledge each claim?
_____	_____	_____	5.	Is a separate file maintained for each claim?
_____	_____	_____	6.	Is each claim being processed and tracked according to the requirements of the specifications?
_____	_____	_____	7.	Has the Resident Engineer reviewed each claim, documented findings, and made a recommendation for resolution?
_____	_____	_____	8.	Have Change Orders been issued for satisfactorily resolved claims? Number_______ Est. Value: $_________
_____	_____	_____	9.	Does any resolved Change Order affect scope of work or lengthen the contract time?
_____	_____	_____	10.	Are there any currently unresolved claims? Number_______ Est. Value: $_________
_____	_____	_____	11.	Are there any anticipated claims?
_____	_____	_____	12.	Are there any resolved Change Orders as a result of field conditions? Number_______ Est. Value: $_________
_____	_____	_____	13.	Are there any pending Change Orders as a result of field conditions? Number_______ Est. Value: $_________
_____	_____	_____	14.	Are there any Change Orders related to the extra work authorized by the Owner? Number_______ Est. Value: $_________

Remarks:

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Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 17
Schedule Monitoring

Project No: ________________ Project Name: ____________________________________

YES	NO	N/A	
_____	_____	_____	1. Has the Contractor's Work Schedule been approved?
_____	_____	_____	2. Does the Contractor's Work Planmatch the established Schedule?
_____	_____	_____	3. Is the Resident Engineer meeting with the Contractor on a regular basis to verify and update the Work Plan and Schedule?
_____	_____	_____	4. What is the current status of the Contract? Contract Time Used: _______%, as of Date: ________ Work Completed: ________%.
_____	_____	_____	5. Was the "Notice to Proceed" issued in accordance with stipulations of the Specifications?
_____	_____	_____	6. Has the Contractor asked for time extensions to the contract?
_____	_____	_____	a. Are time extensions anticipated?
_____	_____	_____	7. Are time extension requests being processed according to the provisions of the Specifications?
_____	_____	_____	8. Are time extension requests based on weather delays in accordance with documented weather conditions in the DIR's?
_____	_____	_____	9. Is there a schedule slippage?
_____	_____	_____	a. Has the Owner been advised?
_____	_____	_____	b. Is there an impact on the schedule and cost?
_____	_____	_____	c. Has the Contractor formulated a "back-on-schedule" plan?
_____	_____	_____	d. Have time extensions been granted? Number ______ Total time _____days

Remarks:

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Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 18

Estimates and Payments

Project No: ____________________ Project Name: ____

YES	NO	N/A	
_____	_____	_____	1. Is there back-up documentation for all pay items?
_____	_____	_____	2. Are monthly payments for quantities in agreement with the Engineer's estimate of quantities for that month?
_____	_____	_____	3. Are items being paid for according to the method of measurement and basis for payment called for in the Specifications?
_____	_____	_____	4. Is the Mobilization Item being paid according to the provisions of the specifications?
_____	_____	_____	5. Is there a separate payment item for stockpiled materials?
_____	_____	_____	6. Are stockpiled materials re-verified in the following month to reconcile quantities with materials incorporated into the work?
_____	_____	_____	7. Do the records indicate when the stockpiledmaterials are incorporated into the work?
_____	_____	_____	a. Was a deduction made for any partial payment amount previously issued?
_____	_____	_____	b. Are equipment and materials storage conditions noted on DIRs?

Remarks:

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Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 19
Daily Inspectors Reports (DIR)

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Are DIR's current?
_____	_____	_____		a. Are Contractor's equipment and labor force clearly documented on DIR's?
_____	_____	_____		b. Are Contractor's hours of work logged?
_____	_____	_____	2.	Is the contract day/date correctly listed on the DIR's?
_____	_____	_____	3.	Is the Owner's Project Number listed correctly?
_____	_____	_____	4.	Is there a DIR for each Construction Inspector on site?
_____	_____	_____	5.	Is the particular operation or location of work clearly identified?
_____	_____	_____	6.	Are all work quantities shown for the work performed each day?
_____	_____	_____	7.	Are Subcontractor's activities clearly documented on respective DIR's?
_____	_____	_____	8.	Is there a separate DIR for each utility, force account crew or DBE working on the project?
_____	_____	_____	9.	Is the DBE Contractor identified as DBE on the DIR?
_____	_____	_____	10.	Are weather conditions and delays adequately noted?
_____	_____	_____	11.	Is the DIR signed and dated by the responsible supervisor?
_____	_____	_____	12.	Are DIR's written in a concise, understandable and legible manner?
_____	_____	_____	13.	Are delays on the project being specifically accounted for?
_____	_____	_____	14.	Are accidents, injuries and damages described on the DIR's?
_____	_____	_____	15.	Are unusual conditions noted? (high water, lane closures, icing, etc.).
_____	_____	_____	16.	Are disputed items of work listed on the DIR?

Remarks: ____

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Reviewer/Date: ____

Resident Engineer/Date: ____

FORM NO. QAP 20

Construction Close-out

Project No: __________________ Project Name: ____

YES	NO	N/A		
_____	_____	_____	1.	Have items on the final "punch list" been accepted and closed out?
_____	_____	_____	2.	Has the final estimate been prepared including pending Change Orders?
_____	_____	_____	3.	Have all pay item quantities on the final estimate been cross-referenced from source documents?
_____	_____	_____	4.	Have the final record plans been completed in accordance with contractual requirements?
_____	_____	_____	5.	Are all incorporated materials and equipment tested and certified according to the requirements of the contract?
_____	_____	_____	6.	Have all contractual incentive/disincentive provisions been correctly applied and administered?
_____	_____	_____	7.	Has the Resident Engineer followed all contractual requirements in accepting the project?
_____	_____	_____	8.	Has the Owner's staff completed any required inspections prior to final acceptance?
_____	_____	_____	9.	Are all project files reviewed before transfer to the required receiver?

Remarks:

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Reviewer/Date: ____________________________________

Resident Engineer/Date: ____________________________________

3 Implementing and Monitoring the QA Program

3.1 Implementing the QA Program

The Unit Manager or his/her representative shall be responsible for implementation and conformance to the QA Program. This may be done by way of regularly scheduled project status meetings, QC reviews, spot checks and interviews with staff, or other means as determined by the Unit Manager. Any deficiencies, errors or non-conformances detected shall be addressed and corrective measures instituted.

PROCEDURE

1. The Unit Manager shall review the work in progress, design documents, records and project files for conformance to established procedures and generally accepted engineering practice. He/she may question staff regarding their knowledge and implementation of the QA Program and shall provide instruction and assistance in its proper applications.
2. Any deficiencies, errors or non-conformances, which may affect the quality of the work shall be immediately brought to the attention of the Project Manager and/or Department Managers. Deficiencies, errors or non-conformances of a minor nature shall be brought to the attention of the individual involved for corrective action.
3. Deficiencies in staff or facilities shall be addressed by the Unit Manager or referred to the Corporate Staff for assistance, as required.

3.2 Monitoring the QA Program

The Quality Assurance Manager shall be responsible for auditing the implementation and conformance to the QA Program. This may be done by way of periodic project audits, spot checks, interviews with staff, or other means as determined by the QA Manager. Any deficiencies, errors or non-conformances detected shall be reported and corrective measures instituted by the Project Manager under the direction of the Unit Manager. Non-conformances should be re-audited to assure compliance.

PROCEDURE

1. The QA Manager shall periodically review projects in progress or recently completed. He/she shall review design documents, records and project files for conformance to the established procedures and general good engineering practice. He/she may question staff regarding their knowledge and implementation of the QA Program and shall provide instruction and assistance in its proper applications.
2. Any deficiencies, errors or non-conformances, which may affect the quality of the work, shall be immediately brought to the attention of the Unit Manager, Project Manager and/or Department Managers. Deficiencies, errors or non-conformances of a minor nature shall be brought to the attention of the individual involved for corrective action.
3. The QA Manager shall review any corrective actions, which have been taken and shall report instances of inadequate action or unresponsiveness to the President for appropriate action.

ATTACHMENT C

Research Description and Findings

Attachment C Research Description and Findings is available on the TRB website at http://trb.org/news/blurb_detail.asp?id=8718.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation